CURRENT TOPICS IN AERONAUTICS

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PREFACE

Aeronautics is an ever-evolving field with only one constant: change. As we stand on the edge of technological advancements, there are still limitless possibilities in skies, and the pioneers and visionaries continue to push the boundaries in the field to shape the future of aviation.

Being motivated by the constant change and thrive to push the limits in aeronautics, this book delves into the heart of current topics in the field, offering a snapshot of the cutting-edge developments that define the present and shape the future. We begin with the history of aviation and its fascinating development with an intention of providing the background achievements leading to todays world. Then, the book continues with delving deep into the current research trends in the field from noise shielding of air vehicles to the use of air vehicles in agriculture, such as for plant protection. Exciting developments in nano materials and polymer matrix composites for the aviation industry were also discussed. Additionally, current research activities for effective joining of aeronautical components were mentioned with a particular focus on the mechanical properties of the resultant aeronautical parts. We also included a chapter on the performance factors of aircraft maintenance personnel considering that maintenance is a key part to realize much safer air travels. In the last section, food safety and quality in aviation, which should not be ignored for commercial jetliners, was emphasized.

Developed countries and major companies always seek to produce new technologies that will make human life easier. Aviation is exactly at the focal point in this matter, and in today's world, the most important sectors that shape the world economy could be considered as foreign trade, tourism, agriculture, space and defense industry, all of which come to life thanks to the aviation sector.

Please fasten your seatbelt and ensure that your seat is in upright position as we embark on a journey through the contemporary aeronautics. The skies above are not just a medium to fly but include a vast history full of hard work, research, innovation, and collaboration. There is possibly no other field like aviation in which the only limit is human imagination. For this, the future is in the skies...

The editors dedicated this book to the 100th anniversary of the Republic of Türkiye. As scientists, we are proud to be citizens of this country.

Assoc. Prof. Dr. Ebru YABAS
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CHAPTER 1

HISTORY OF AERONAUTICS

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1. INTRODUCTION

Mankind always had the ambition to fly, which might be originated by scientific curiosity, imagination, inspiration through observing birds, desire to explore and conquer the skies or combination of all these. As could be expected, the first attempts of flight were based on mimicking birds. For instance, Leonardo da Vinci studied the anatomy and flight patterns of birds, and proposed several ideas to design a flying machine, all of which were based on flapping wings (Petrescu et al., 2017). Eventually, in 1799, Sir George Cayley proposed for the first time that an air vehicle should be composed of a fixed wing for generating lift, a separate propulsion system, and a horizontal and vertical tail for stability (Vos, Rizzi, Darracq, & Hirschel, 2002). However, there were no suitable propulsion systems at that time considering that steam engines were too heavy for flight purposes. Thus, the inventions of internal combustion engine in 1863, and the four stroke gasoline engine in 1885 could be considered to be the main developments that made flight a much achievable ambition. Apparently, once flying became a reality, the exploration of the skies reshaped the way we perceive the world, and forged a path toward unlimited innovation. In this chapter, we provided the brief history of aeronautics with a particular focus on developments in aeronautical materials. The major milestones in the aeronautical history were provided chronologically by highlighting the pioneers and visionaries whom compelled the boundaries to make countless possibilities a reality.

2. EVOLUTION OF AERONAUTICS WITH TIME

The term aviation comes from the Latin word avis which means bird with the suffix of -ation with the meaning of action or progress (Dictionary, 2023). The history of aviation is actually older than 2000 years. Some sources highlight kite, which was invented in China by Mo Zi and Lu Ban at around 500 BCs, as the first man-made air vehicle (Crouch, 2003; Rudowicz, 2004). Afterwards, man-lifting kites could be highlighted in the history of aviation. Similar to kite, the first records on man-lifting kites were also from China (Encylopedia, 2022). Also, there exists information regarding the use of man-lifting kites in Japan, such as the story of Japanese Ishikawa Goemon, whom was believed to steal golden scales from the top of the Nagoya castle by using a man-lifting kite (Encylopedia, 2022). Figure 1 shows an illustration for the man-lifting kites.

Figure 1. Illustration of man-lifting kites (Museums).

Regarding the first aerostatic flight in history, one could mark 1783. At that time, Joeseph and Stephen Montgolfier invented the hot air balloon by which the first aerostatic flight was performed. The first hot air balloon was made up of cotton canvas with paper glued onto both sides, had dimensions of 18.47m x 13.28m, weighed 400 kg, used a combination of straw and wool as the fuel, and the first passengers to fly with it were a rooster, a duck, and a sheep due to safety measures (Cohen, 2022). This hot air balloon or so-called the Mongolfier's balloon is illustrated in Figure 2. Basically, balloon flight, which could also be regarded as lighter-than-air flight, involves use of gas burners to heat the air enclosed in an envelope, and depends on the three principles of buoyancy, which were Archimedes' principle, Boyle's Law, and Charles's Law.

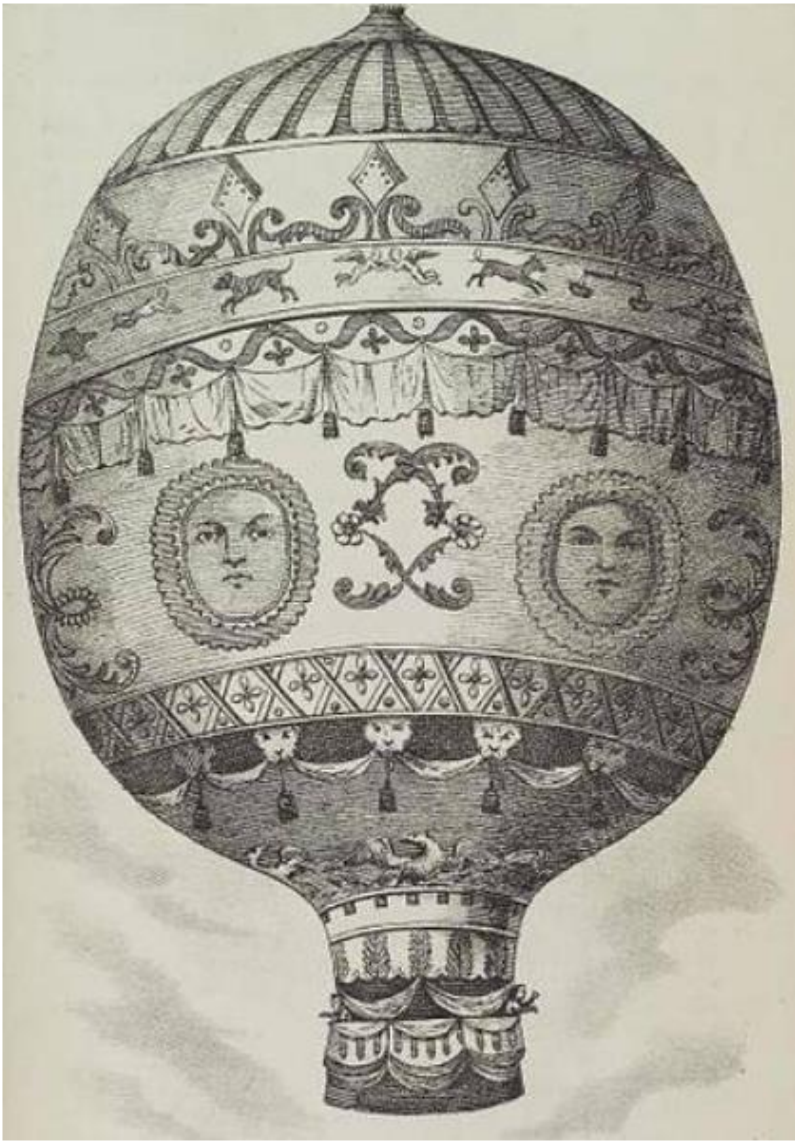

Figure 2. Illustration of Mongolfier's balloon (Wise, 1850).

After the success of Mongolfier’s baloon, the main developments in the field were particularly on to improve the fuel and envelope materials. With time, the burning straw in Mongolfier’s baloon was replaced with coal gas, petroleum, and propane, and the envelope materials evolved from paper to silk, nylon, and polyester (Curley, 2012). In the 20th century, high altitude balloons with specific practical applications, such as aerial photography, were designed thanks to the development of pressurized suits and cabins (Curley, 2012).

Figure 3. Illustration of Hindenburg zeppelin ("Hindenburg LZ129," 1936).

Another pioneering development in the field emerged with the invention of airships, or so called zeppelins. In fact, both hot air balloons and airships could be considered as lighter-than-air flight vehicles. However, the two systems have major differences as well. For instance, the envelope of hot air balloons is made of heat-resistant fabric, while the airships have rigid structures, which allows better control and flight stability. More importantly, the hot air balloons are not powered, and their movement is determined by the wind and the temperature of the air inside the envelope. On the other hand, airships are powered with engines, and hence they can navigate more precisely. Hydrogen and helium were the most common gases that were used to lift the airships, and the very first rigid airship named Luftschiff Zeppelin 1 (LZ-1) was constructed in 1897 by Count Ferdinand von Zeppelin in Germany (Curley, 2012). The airships were used for both civilian and military purposes, including passenger air travel, long-distance flights, and reconnaissance. Still, the airships had major drawbacks, including their high cost, slow speed, vulnerability to stormy weathers, and their use declined particularly after the Hindenburg disaster in 1937 (Curley, 2012). Hindenburg (Figure 3) was the largest airship ever built, and was filled with highly flammable hydrogen gas when it burst into flames during landing at New Jersey on its maiden transatlantic voyage (Curley, 2012).

Regarding heavier-than-air flight, the three major challenges in the early 1900s were construction of sustaining wings, generation and application of the necessary power, and the balancing and steering of the air vehicle during flight. Finally, the very first powered, controlled, and sustained flight was performed by Orville and Wilbur Wright with Wright Flyer (Figure 4) on December 17, 1903 (Crouch, 2018).

Figure 4. A model of the Wright Flyer from the Frontiers of Flight Museum at Dallas Love Field, Dallas, Texas, USA (Barera, 2015).

Afterwards, the developments in the field became much more rapid, particularly following the very first use of air vehicles in active combat during the Italo-Turkish war in 1911. At that time, the Italians used a warplane to drop grenade bombs to Turkish positions for the first time in history (Guilmartin & Taylor; Hu et al., 2020). Considering that air vehicles could devastate enemy positions from air, and the fact that two great wars occurred during the first half of the 1900s, the advancement of the aviation technology was further accelerated. Between 1920 and 1930, the major advancements were particularly on the aircraft design and navigation, and the very first non-stop transatlantic flight was performed in 1927. In 1930, turbojet was invented, and Heinkel He 178 of German origin became the first turbojet powered aircraft in history (Meher-Homji & Prisell, 2000). At the time of World War II, fighter, bomber, and reconnaissance aircrafts were became widespread.

Figure 5. The first jetliner in history: British de Havilland Comet (Menendez San Juan, 2008).

Following the World War II, commercial aviation began to rise which transformed the travelling by making air travel much faster and accessible. In this sense, British de Havilland Comet, which shown in Figure 5, became the first commercial jet airliner (Mainardi, Maggioni, & Zanchin, 2019). Early designs of commercial jet aircrafts had serious structural and design problems, causing catastrophic failures. For instance, first commercial jets had square shape windows. However, cabin pressures were concentrated on the edges of the square shaped windows in such designs resulting in a two to three times higher pressure at these points than the rest of the fuselage, and hence causing catastrophic accidents due to the so-called stress concentration cracking. Overall, with time and research & development activities, more reliable commercial jetliners were developed, such as Boeing 707 which could be considered as the first commercially successful jet airliner. The first Boeing 707 prototype was tested in 1954, and the jetliner entered service in 1958. In fact, Boeing was not a popular company for commercial aviation in the late 1940s, and there were no orders to the products of Boeing in 1952. Even in 1955, there were still no orders to Boeing products, including Boeing 707. After an impressive test flight at the same year during the annual speed boat races, the very first order was received from Pan Am airline, leading the way to the success for Boeing 707 (Glancey, 2014).

3. EVOLUTION OF AVIATION MATERIALS WITH TIME

One of the critical points in development of aviation technology is materials science. Apparently, air vehicles are composed of many components, all of which are made up of various materials. Obviously, a material should exhibit the necessary mechanical and functional properties to perform their intended functions. In fact, materials could typically be categorized into four main groups: ceramics, metals, polymers, and composites. Each material possesses distinct advantages and disadvantages, contingent upon its application. Throughout human history, various materials have found application in aviation. A notable contrast emerges between the materials initially employed in aircraft and those utilized in contemporary aviation (Callister Jr. & Rethwisch, 2018; Egbo, 2021; Shiva, 2017).

It is well-established that metallic materials, predominantly titanium alloys, steel alloys, aluminum alloys, nickel-based alloys, and magnesium-based alloys were extensively employed in historical aviation applications. However, advancements in material technology have brought about changes in the composition of aircraft structures. While steel continues to hold significance in the aviation industry, the utilization of aluminum and its alloys has gained prominence as a substitute for steel, attributed to its lower specific gravity. Among metallic materials used in aviation applications, Titanium alloys and aluminum alloys emerge as the most prevalent choices, reflecting the ongoing evolution in material preferences for aircraft construction (Belan, Vaško, & Kuchariková, 2017; Callister Jr. & Rethwisch, 2018; Tanasa & Zanoaga, 2013). Table 1 lists the various materials used in fighter aircrafts for comparison.

Table 1. Percentage by weight of materials used in the 18E/F and 18C/D fighter aircrafts (Das, Sahu, & Parhi, 2019; Quilter, 2001).

Materials	18E/F (%)	18C/D (%)
CFRP	19	10
Steel alloys	14	15
Aluminum alloys	31	49
Titanium alloys	21	13
Others	15	13

Strength and lightness represent the pivotal criteria in the material selection for aircraft fuselage construction. Moreover, composite materials, exhibiting high rigidity, thermal stability, and corrosion resistance, emerge as structures encompassing all these desirable attributes (Callister Jr. & Rethwisch, 2018; Hasan, Zhao, & Jiang, 2019). Composite materials find extensive use, particularly in aircraft, owing to their exceptional mechanical properties, chemical characteristics, and ease of processability. A paramount factor in their widespread adoption is the high strength-to-weight ratio exhibited by composite materials. Their inherent flexibility and resistance to vibrations enable designs that withstand fatigue, a common challenge in metallic structures. Composite materials offer advantages over metals in terms of corrosion resistance, and their high surface resistance stands as another crucial benefit. Furthermore, the preference for composite materials in aviation applications is influenced by their low toxicity and fire resistance (Tanasa & Zanoaga, 2013). These materials also draw attention for their capacity to stretch easily before experiencing tensile cracks. The reduction of weight in aircraft yields numerous advantages. In commercial aviation, where aircraft transport passengers or cargo, it facilitates longer distances with reduced fuel consumption. In the case of military aircraft, it allows for increased payload capacity, enabling the carriage of more ammunition and fuel for extended ranges (Callister Jr. & Rethwisch, 2018; Carlsson, Adams, & Pipes, 2013; Das, Sahu, & Parhi, 2021; Parveez et al., 2022; Zabihi, Ahmadi, Nikafshar, Preyeswary, & Naebe, 2018).

In the contemporary aviation landscape, aircraft necessitate materials that exhibit compatibility with atmospheric conditions and possess a biodegradable structure. Composite materials emerge as the most suitable material group to fulfill this requirement, contributing to the growing utilization of composites in the aviation industry. These materials find frequent application in various aircraft components, including wings, fuselages, tails, and doors. Moreover, the heightened interest in composite materials within the aviation sector has been spurred by their successful deployment in space applications, particularly in missiles (Godara, Yadav, Goswami, & Rana, 2021; Tanasa & Zanoaga, 2013). Approximately 50 years ago, the commercial use of composite materials in the aviation industry stood at around 5%. However, today, this figure has surged to over 50%, highlighting the remarkable increase in the adoption of composite materials in aviation (Abbas, Li, & Qiu, 2018). As an illustrative example of this trend, the evolution of composite structures utilized in Boeing passenger aircraft over time is presented in Table 2.

Table 2. Composite structure of Boeing (Aly, 2017; Boyer, 1992; Das et al., 2021).

	Boeing 787	Boeing 777	Boeing 757/767	Boeing 747
Composites	50%	12%	3%	1%
Aluminum	20%	50%	-	-

Another example could be from the Airbus since A300 aircraft was composed of only 8% composite materials by weight in 1975. Today, this proportion has surged to 53% in the Airbus A350 aircraft, underscoring a significant increase in the integration of composite materials over the years (Tanasa & Zanoaga, 2013; Trzepieciński et al., 2021). Overall, composite materials, holding a crucial role in aviation applications, continue to advance with each passing day, propelled by technological breakthroughs. Recent strides in research on carbon nanotube materials have injected fresh momentum into the development of composites (Godara et al., 2021).

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CHAPTER 2

DIFFRACTION METHODS APPROACH TO THE NOISE SHIELDING OF AIR VEHICLES

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1. INTRODUCTION

The civil air transportation industry, which has been gradually developing over the past several decades, is crucial to today's globalized society. However, because of ecological issues, this expansion's sustainability is a problem. As noise poses a significant threat to human health, along with greenhouse gas emissions, airport capacity is restricted, and curfews are put in place at night. Therefore, noise is a key design factor for future aircraft, and precise noise forecasts are essential early in the design process. An aircraft's overall noise emissions present a challenging issue because its various parts each create noise with distinctive properties. Early in the design process, high fidelity methods are computationally time- and resource-intensive, and less complex approaches, like semiempirical methods, are frequently thought to be more appropriate (Vieira 2021).

The aircraft's wings and fuselage can shelter engine noise, which can remarkably lessen how loud it is perceived on the ground. Due to the size of the fuselage, most studies on noise shielding are focused on Blended Wing Body (BWB) types. Even so, when the engines are positioned above the wings in conventional tube and wing designs, noise shielding is also thought to be important. As a result, it's critical to have a noise shielding technique which can be applied to several aircraft geometries without reducing forecast accuracy or producing extremely slow calculations (Vieira et al. 2017).

Future aircraft designs frequently incorporate the idea of noise shielding, which reduces noise on the ground by partly isolating engine noise from the airframe. The Kirchhoff integral (KI) and the Modified Theory of Physical Optics are the foundations of the noise shielding predictions made in this article (MTPO). This approach was broadened to consider noise sources other than monopoles and to compute creeping rays produced by smooth edges (Umul 2004)

2. IMPACT OF AIRCRAFT NOISE

Civil aviation plays an important role in the world economy and globalization. Air traffic has been continuously rising together with the passenger growth rate since its early days in the 1960s (ICAO Environmental Report 2007). Despite the necessity of civil aviation in contemporary life, its emissions of greenhouse gases and noise have a detrimental effect on the environment (E. Ahyudanari 2019), (Taptich et al. 2016) and people's health (Basner et al. 2019), (Rojek et al. 2019).

The increase in engine bypass ratio (Hall 2009), which significantly lowered the jet contribution to the overall noise output and decreased the perceived noise level by 20 dB over the decades as shown in Figure 1, was the first step toward more silent aircraft. It was implemented in the 1970s. Another successful approach for lowering engine noise is the acoustic treatment of engine ducts with liners (Hughes et al. 1990), which uses the Helmholtz resonator principle to attenuate frequencies of interest.

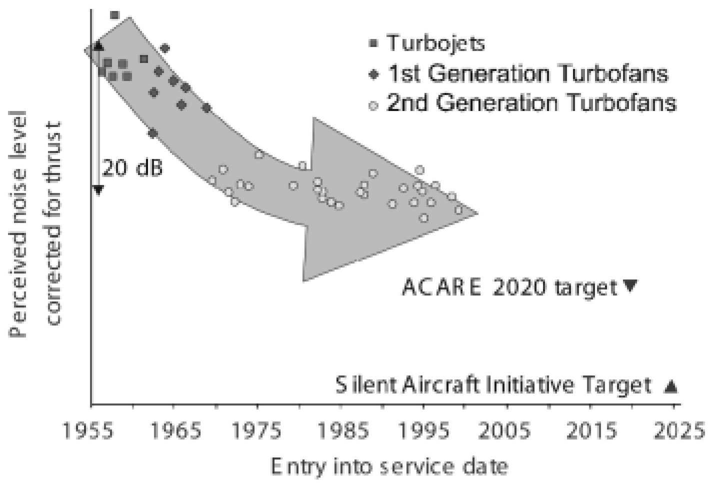

Figure 1. Evolution of engine noise (Hall 2009).

As engine noise decreased, airframe noise sources, such as high-lift devices and the landing gear, became more important during landing (Lilley 2001). A balanced approach to reduce airframe noise without negatively affecting the aerodynamic performance of the high-lift devices and the landing gear proved to be a difficult task (Dobrzynski 2010). However, these materials are still not certified for aircraft operations. Side-edge fences and flow transparent edge replacements (Angland et al. 2009) (using porous metal foams) demonstrated encouraging results in lowering the noise produced by flap side edges. Another piece of technology that has the potential to lessen airframe noise is slat coverings (W. Dobrzynski et al. n.d.). Most of these airframe noise reduction methods have been put through wind tunnel tests as well as more recent in-flight trials (Yamamoto et al. 2019).

3. LOW NOISE AIRCRAFT

Despite all the efforts towards more silent flight operations around airports, the noise reduction targets for 2050 are far from being met. The prospect of a continuous growth of the number of passengers along with a more critical perception of noise and its effects on human health anticipate increasingly strict noise regulations. It is therefore questionable whether noise emissions of conventional aircraft can still be significantly further decreased (Vieira 2021).

Due to such constraints, unconventional aircraft are increasingly seen as alternatives capable to meet noise regulations' targets. The Blended Wing Body (BWB) aircraft is perhaps the first concept that comes to mind, due to its distinct airframe. This concept is being considered as an option for long range operations since the early 2000s due to its aerodynamic efficiency, low noise emissions and reduced direct operating costs (Okonkwo et al. 2016). The different variations of the BWB aircraft include disruptive technologies such as distributed propulsion (positioned at the rear fuselage) and laminar flow technology. BWB concepts are more silent than conventional wing and tube aircraft because they do not require flaps and a tailplane, and engine noise is significantly shielded by the airframe (Katsurayama et al. 2015). These features make the BWB aircraft an attractive concept for the industry, and many joint initiatives explored different variations of this concept, as illustrated in the examples of Figure 2. Nevertheless, several challenges still remain, such as stability and control problems and interactions between the airframe and the propulsion system (Vieira 2021).

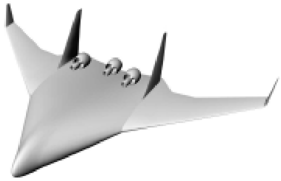

Figure 2. BWB aircraft variations investigated in the scope of the Multidisciplinary Optimisation of a Blended Wing Body (MOB) project (Morris et al. 2004).

Other unconventional aircraft, such as delta, truss-braced and strut-braced configurations, were also investigated as low noise alternatives to conventional commercial aircraft (S. Mistry 2008). The Low Noise Aircraft of the German Aerospace Center (DLR), represented in Figure 3, is an example of an unconventional aircraft that does imply such a drastic design change compared to today's aircraft as the BWB does. This design relies, like the BWB, on noise shielding to reduce engine noise by mounting the engines above the forward-swept wings. The wings are shifted backwards to reduce cabin noise, the vertical tail plane is substituted with double fins (also to benefit from engine noise shielding), and the canard arrangement stabilizes the model (Werner-Westphal et al. 2008).

Figure 3. Top view of a scale model of DLR's Low Noise Aircraft in the Low-speed wind tunnel Braunschweig (NWB) operated by the foundation Deutsch-Niederländischer Windkanal (DNW) (German Aerospace Center (DLR) 2019).

Less disruptive ideas are more likely to be adopted by the industry over the next few decades than more radical ones. Examples include tube and wing aircraft with rear mounted engines, which also showed promising results in reducing noise pollution in communities (Bertsch et al. 2014). These configurations rely on engine noise shielding and make use of airframe noise reduction technologies to decrease the noise footprint on the ground.

4. DEFINITION OF MODIFIED THEORY OF PHYSICAL OPTICS (MTPO) AND NOISE SHIELDING WITH MTPO

Newton offered one of the earliest explanations for the phenomenon of wave diffraction (Pelosi et al. 1998). His view states that as light is made up of particles, diffraction happens as a result of the compelling influence of discontinuities on the particles. With his famed double slit experiment, Kirchhoff later demonstrated that light acts like a wave, but he was unable to mathematically characterize this (Young 1802). Fresnel's mathematical language accurately described how light behaved (Rubinowicz 1957). Sommerfeld's study on the idea of dispersion was groundbreaking (Sommerfeld 2004).

By using a conducting half-plane lit by a plane wave, he was able to precisely solve the scattered fields in terms of Fresnel functions. The solution of the Helmholtz wave equation is typically used to explore the scattering of waves by objects while taking boundary conditions into account. High frequency asymptotic methods, on the other hand, are desirable if the scatterer's structure cannot be broken down into its coordinates (A. K. Bhattacharyya 1995). There are essentially two branches of high frequency techniques. Geometric optics and the geometrical theory of diffraction are part of the first group of raying-based techniques, whereas physical optics, the physical theory of diffraction, the modified theory of diffraction, and other topics are part of the second group of current-based techniques (Umul 2004, G. L. James 2007, KELLER 1962, Ufimtsev 2006).

The induced surface currents produced by the incident waves hit on the scatterer can be measured using the current-based methods in order to determine the dispersed fields. In the literature, PO technique is commonly cited and especially effective for metallic objects (Stutzman et al. 1981, C. A.

Balanis 2012, Basdemir 2015). The stationary phase evaluation of the scattering integral yields the GO waves. On the other hand, when the scattering integral is evaluated using the edge point technique, PO approach predicts incorrect contribution of edge for the scattered field. Its definition is where this flaw comes from. The shadow areas are not considered by the PO method; only tackled illuminated surface.

Correction terms have been used to try and fix the PO method's flaw (A. K. Bhattacharyya 1995, G. L. James 2007, KELLER 1962, Ufimtsev 2006, Stutzman et al. 1981, C. A. Balanis 2012, Basdemir 2015, P. Ya. Ufimtsev 2003). In these techniques, the contribution of the uniform part of the scatterer is evaluated by using the PO approach, and then multiply or add a correction term to the formula to get the right diffracted field. These techniques work and produce accurate answers. Nevertheless, still addition or multiplication operations happen outside of the scattering integral so they are just temporary fixes. Additionally, the precise form of the adjustment terms has not yet been established and they are still contingent on the resolution of existing issues. It implies that the correction terms cannot be obtained unless the precise solution to the issue is known. In contrast to other approaches already in use, MTPO solves the scattering problem without the need for additional correction terms. Using adjustments made to the scattering integral's kernel to identify the proper diffracted fields, this approach yields the answer. Three axioms provide the foundation for the method's implementation. The first one takes the scattering surface into account while determining the angle of scattering. The second one is the creation of a brand-new variable unit vector. The variable unit vector is located between the incident and scattered rays (reflected or transmitted) and divides the angle between these rays into two equal halves. The final postulate takes the aperture and scattering surface into account simultaneously (Basdemir 2018).

The edge field contribution to the diffracted wave is connected to the first axiom. The angles of incident and scattering are assumed to be equal to each other in the classical PO. As a result of this acceptance, continuous surface is assumed to be an extension of discontinuous surface. Therefore, at the edge discontinuity, the evaluation of the scattering integral is unsuccessful. The contribution of all scattering locations is connected to the second axiom. With the exception of stationary phase and edge points, all contributions to the PO utilizing the classical unit vector have been cancelled. The static unit normal vector can be used as a variable to assess each point's contribution at the observation location. The incident diffracted field is related to the final axiom. The PO technique ignores the aperture section and just considers the lighted surface. This consideration assesses the incident diffracted fields but excludes information on the reflected diffracted fields. Consequently, the achieved diffracted field values are unreliable. Through asymptotic evaluation of the scattering integral, the MTPO technique leads to accurate diffracted field values (Basdemir 2018).

5. DETAILED ANALYSIS OF AXIOMS

As stated in the previous section, MTPO adjusts the scattering integral's kernel rather than requiring additional correction terms. The Fermat principle states that rays reflect at an angle that is equal to their angle of incidence. Only one ray, though, reflects at the discontinuity point at the same angle. Fig. 4 shows this process.

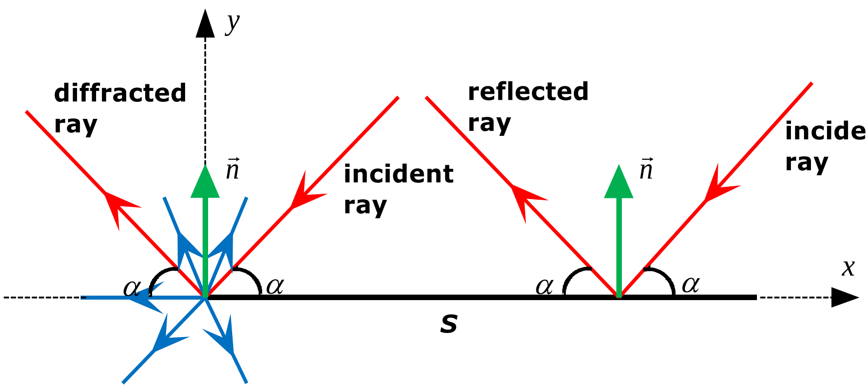

Figure 4. The process of reflection in terms of Fermat principle (Basdemir 2018).

In Figure 4, n represents the static unit normal vector, and represents the angle of incidence and reflection. There are multiple rays at the discontinuous spot. Keller's GTD provided the answer (G. L. James 2007). The Modified

Fermat Principle states that the angle of reflection should be regarded as changeable (MFP). Franceschetti also makes this point (G. Franceschetti 1997). Both the scalar and vectorial forms of the scattering integrals can be expressed as

$$\vec{E} = \frac{-j\omega\mu_0}{4\pi} \iint_{S'} \vec{J}_{PO} G dS' \tag{1}$$

and

$$u(P) = \frac{1}{4\pi} \iint_{S'} [u\nabla G - G\nabla u] \cdot \vec{n} dS' \tag{2}$$

where ω and μ_0 are the radial frequency and free space permeability respectively. The term J_{PO} is the PO surface current and G represents the Green's function. In Eq. (2), u is the total field and P shows the observation point. The comparison of both integrals yields the mutual term as n. It is clear that n is used both for derivation of PO current and the kernel of the scattering integral. The current term in the traditional PO technique can be calculated by the vector product of total magnetic field with the unit normal vector. The angles of incidence and reflection can be taken as equal if these integrals are evaluated for the uniform part of the scatterer by using the stationary phase approach in accordance with the above-mentioned geometry. As a result, the Fermat principle accurately predicts GO waves. The angle of scattering does not equal to the angle of incidence at the discontinuities, it is noted when the integrals are assessed using the edge point method. Diffracted fields must therefore abide by the MFP laws. As a result, it is revealed that the problem is caused by the definition of unit normal vector and the classical representation is invalid at the diffraction point. Instead of using the traditional method, a variable unit vector that divides the angle between the incident and scattered waves into two equal angles can be defined to fulfill the Fermat and MFP. The method is shown in Fig. 5 (Basdemir 2018).

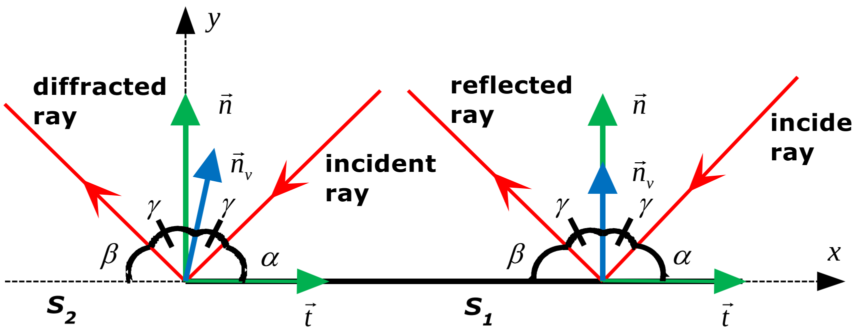

Figure 5. Definition of variable unit vector and scattering angle (Basdemir 2018).

By using the scattering angle and unit vector as variables, it can be demonstrated that the Fermat principle is satisfied at the reflection point and the MFP is satisfied at the edge point. The real tangential and normal unit vectors of the surface are denoted by t and n, respectively. The PEC surface S_1 and the aperture S_2 are represented, respectively, by the letters S_1 and S_2. The expression of the variable unit normal vector n_v is,

$$\vec{n}_v = cos(u + \alpha)\,\vec{t} + sin(u + \alpha)\,\vec{n} \tag{3}$$

where the angle u is written as

$$u = \frac{\pi}{2} - \frac{\alpha+\beta}{2} \tag{4}$$

In relation to incident and incident distributed fields, the final axiom is stated. The surface current induced by the incident wave on the uniform part of the scatterer can be integrated to produce the reflected and reflected diffracted fields. However, this operation provides no data regarding incident and incident diffracted fields. Therefore, aperture part has to be considered. For the Equivalence Source Theorem (EST), equivalent currents can be defined on the aperture, and scattered fields can be produced by integrating the currents defined on the aperture S_2. Same procedure is valid for analyzing the radiation from aperture antennas (Jull 1981). As a result, the information of incident and incident diffracted fields is in the integration of the designated current. We can describe a surface current that is induced on S_1 as

$$\vec{J}_{es_1} = \vec{n}_v \times \vec{H}_t\Big|_{S_1} \tag{5}$$

where H_t is the surface's overall magnetic current density. The specified on S_2 equivalent electric and magnetic surface currents are written as

$$\vec{J}_{es_2} = \vec{n}_v \times \vec{H}_i\Big|_{S_2} \tag{6}$$

and

$$\vec{J}_{ms_2} = -\vec{n}_v \times \vec{E}_i\Big|_{S_2} \tag{7}$$

where E_i, H_i, are, respectively, the aperture's incident electric and magnetic field intensities. Incident and reflected dispersed fields make up the scattered field. Eq. (5)'s evaluation of surface current results in reflected scattered fields, while Eqs. (6) and (7)'s evaluations of surface currents result in incident scattered fields. As a result, the scattering integral for the incident scattered field is given by,

$$\vec{E}_{is} = -\frac{j\omega\mu_0}{4\pi}\iint_{S_2}\vec{J}_{es_2}GdS' + \frac{1}{4\pi}\iint_{S_2}\nabla \times \vec{J}_{ms_2}GdS' \tag{8}$$

and scattering integral for the reflected scattered field is written as

$$\vec{E}_{rs} = -\frac{j\omega\mu_0}{4\pi}\iint_{S_1}\vec{J}_{es_1}GdS' \tag{9}$$

for an E-polarized incident wave (Basdemir 2018).

6. APPLICATION TO THE SOFT HALF-PLANE

The issue under discussion is shown in Fig. 6. The tangential component of the total electric field intensity on the surface of the half-plane is equal to zero, which is known as the Drichlet boundary condition. The problem can be assumed to be a 2-D situation because the half-plane is symmetric along the *z* axis, and the surface integral can be transformed into a line integral (Ufimtsev, 2006).

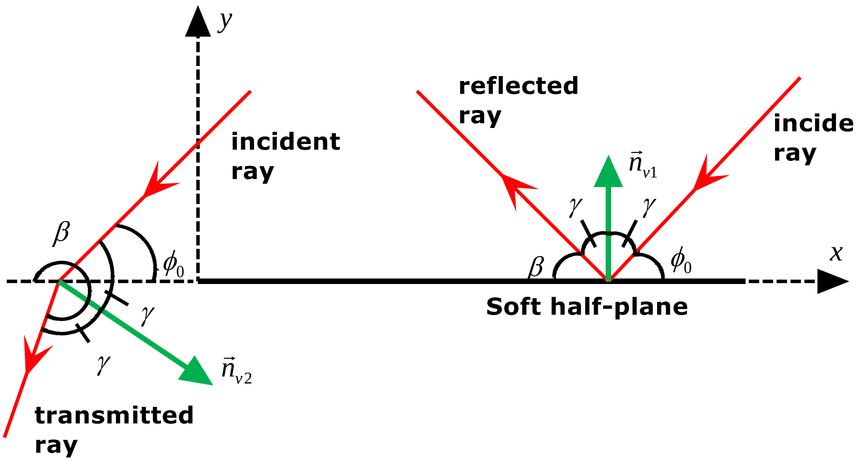

Figure 6. The geometry for a soft half-plane illuminated by a plane wave (Basdemir, 2018).

Hence, Eq. (13) can be written as

$$\vec{E}_t = \vec{E}_i + \frac{kZ_0 e^{j\frac{\pi}{4}}}{2\sqrt{2\pi}} \int_{x'=0}^{\infty} \left[2\vec{J}_{es_2} - \vec{J}_{es_1}\right] \frac{e^{-jkR}}{\sqrt{kR}} dx' \tag{14}$$

where k and Z_0 are the wavenumber and impedance of the free space respectively. R is the ray path and expressed as

$$R = \sqrt{(x - x')^2 + y^2}\ . \tag{15}$$

The half plane is illuminated by the plane wave of

$$\vec{E}_i = \vec{e}_z E_0 e^{jk(x\cos\varphi_0 + y\sin\varphi_0)} \tag{16}$$

where ϕ_0 is the angle of incidence, also E_0 is the complex magnitude. The magnetic field intensity accompanying to incident electric field can be derived as

$$\vec{H}_i = -\frac{E_0}{Z_0}\left(\vec{e}_x \sin\varphi_0 - \vec{e}_y \cos\varphi_0\right) e^{jk(x\cos\varphi_0 + y\sin\varphi_0)} \tag{17}$$

by using Maxwell-Faraday equation. The variable unit vectors are defined by

$$\vec{n}_{v1} = \vec{e}_x \cos(\gamma + \varphi_0) + \vec{e}_y \sin(\gamma + \varphi_0) \tag{18}$$

where u is equal to $\pi/2-(\phi_0+\beta/2)$ and

$$\vec{n}_{v2} = \vec{e}_x \cos(\gamma - \varphi_0) - \vec{e}_y \sin(\gamma - \varphi_0) \tag{19}$$

where u is calculated as $-\pi/2+(\beta-\phi_0/2)$ from the geometry given in Fig. 3 and β is the angle of scattering. Hence, considering Eqs. (5), (6) and (17) the induced surface currents are derived as

$$\vec{J}_{es1} = \frac{2E_0}{Z_0} \sin\left(\frac{\beta+\varphi_0}{2}\right) e^{jkx'\cos\varphi_0} \vec{e}_z \tag{20}$$

and

$$\vec{J}_{es2} = \frac{E_0}{Z_0} \sin\left(\frac{\beta-\varphi_0}{2}\right) e^{jkx'\cos\varphi_0} \vec{e}_z \tag{21}$$

Inserting Eqs. (20) and (21) into Eq. (14) and separating the scattering integral as incident and reflected scattered integral, Eq. (14) can be rewritten as

$$\vec{E}_{is} = \vec{E}_i + \vec{e}_z \frac{kE_0 e^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \int_{x'=0}^{\infty} \sin\left(\frac{\beta-\varphi_0}{2}\right) e^{jkx'\cos\varphi_0} \frac{e^{-jkR}}{\sqrt{kR}} dx' \tag{22}$$

and

$$\vec{E}_{rs} = \vec{e}_z \frac{kE_0 e^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \int_{x'=0}^{\infty} sin\left(\frac{\beta+\varphi_0}{2}\right) e^{jkx' cos\, \varphi_0} \frac{e^{-jkR}}{\sqrt{kR}} dx' \tag{23}$$

The variable transformation of

$$\eta = \sqrt{k[R - x' cos\, \varphi_0 + \rho\, cos(\varphi - \varphi_0)]} \tag{24}$$

can be applied to the integral of Eq. (22). After this transformation the expression of

$$\vec{E}_{is} = \vec{e}_z e^{jk\rho\, cos(\varphi-\varphi_0)} F[\xi_-] \tag{25}$$

is obtained where *F* [x] is the well-known Fresnel function. By using similar procedure, the variable transformation of

$$\eta = -\sqrt{k[R - x' cos\, \varphi_0 + \rho\, cos(\varphi + \varphi_0)]} \tag{26}$$

is applied to integral of Eq. (23). Thus, the transformation reads,

$$\vec{E}_{rs} = -\vec{e}_z e^{jk\rho\, cos(\varphi-\varphi_0)} F[\xi_+] \tag{27}$$

where detour parameters are given as

$$\xi_{\pm} = -\sqrt{2k\rho}\, cos \frac{\varphi \pm \varphi_0}{2} \tag{28}$$

The changes described in Equations (24) and (26) apply to Equations (29) and (14) of Reference (Umul 2008). It is evident that MTPO provides an accurate solution to the half-plane problem for conducting surfaces (Basdemir 2018).

7. NUMERICAL RESULTS

The outcomes of the MTPO integrals will be examined in this section. It was demonstrated in the preceding section that the MTPO provides the exact answer to the problem of conducting half-plane. The wavenumber *k* is taken as 2π/λ where λ is the wavelength and is equal to 0.1. *ρ* is the distance between origin and the observation point which is taken as 6λ. The incidence angle ϕ_0, is taken as 60°. Figure 4 shows the well-known scattered field by a soft half-plane (Basdemir 2018).

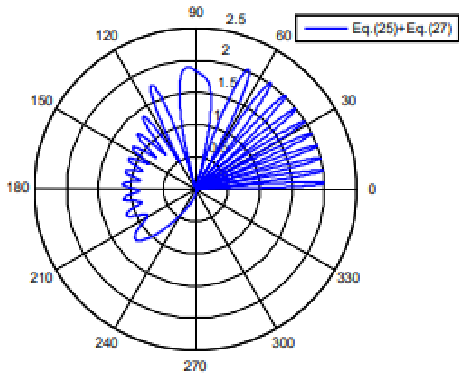

Figure 7. Total Scattered Field (AsianubaIfeoma.B. et al. 2021).

The plots are used to compare MTPO with PO (polar and rectangular). Due to the inclusion of the aperture surface, the plot shows that MTPO has less side lobe radiation than PO (second surface). Due to distance (d), which is directly proportional to the main and side lobes, it was possible to compute edge diffraction and lower major lobe. The distance (d) being discussed here is the one between the reflecting surface and the focus antenna. The polar and rectangular graphs that show how MTPO and PO are compared are shown below (AsianubaIfeoma.B. et al. 2021).

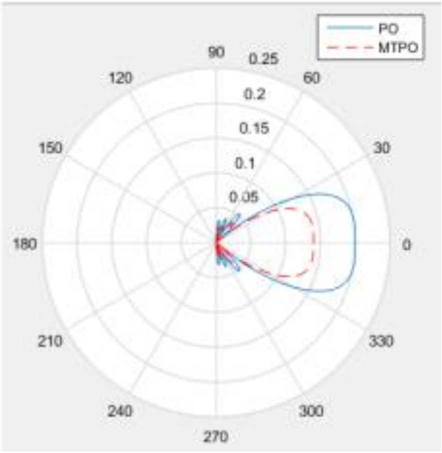

Figure 8. Comparism between MTPO and PO (AsianubaIfeoma.B. et al. 2021).

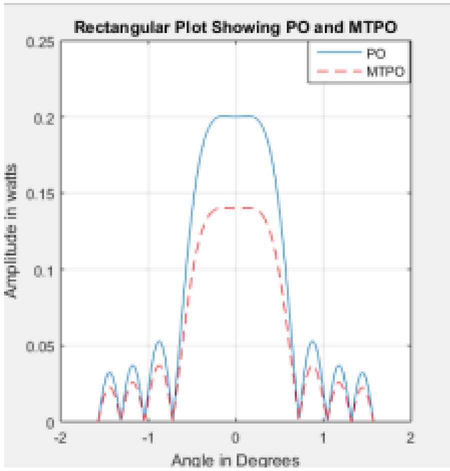

Figure 9. Rectangular plot showing MTPO and PO (AsianubaIfeoma.B. et al. 2021).

8. CONCLUSIONS

Axioms of MTPO were reexamined in this chapter. Three axioms form the basis of the approach. The first of them is considering the angle of scattering as variable. The second of them is based on the definition of variable unit vector, and the last one considering the aperture component. It is mentioned that the definitions and the soft half-plane was considered as an application. When the required variable transformations are accomplished, it has been demonstrated that the approach provides the perfect solution for conducting half plane problems (Umul 2017). When MTPO and PO were compared, it was discovered that PO has more side lobes than MTPO. The reduction of the side lobes by MTPO is due to the addition of the aperture surface (second surface) (AsianubaIfeoma.B. et al. 2021). It is concluded that the diffraction methods especially yield exact results such as MTPO can be implemented quite successfully to not only the noise shielding but also for the reduction methods of radar eco signals.

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CHAPTER 3

ROCKET PROPELLANTS

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1. INTRODUCTION

This chapter provides information on the definition, brief history, classification, essential properties, and new developments of rocket propellants. A rocket is just a chamber that holds pressurized gas. A narrow aperture located at one extremity of the chamber permits the gas to be released, generating a force that pushes the rocket in the reverse direction. An exemplary illustration of this concept is a balloon, as shown in Figure 1. The air contained within a balloon is subjected to compression due to the elastic properties of the balloon's rubber walls. The air exerts a counteracting force to achieve equilibrium between the interior and exterior pressures. Upon releasing the nozzle, air is expelled through it, resulting in the propulsion of the balloon in the opposite direction. Rockets and balloons are seldom associated with our thoughts. However, our focus is on the huge vehicles responsible for transporting satellites into orbit and spaceships to celestial bodies such as the Moon and planets (Shearer, 2008).

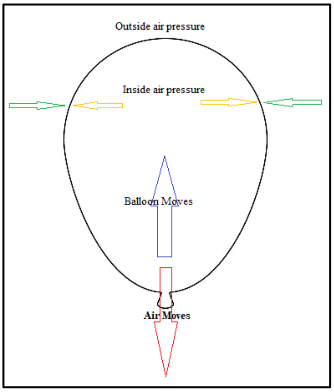

Figure 1. The motion of a rocket

The history of rocket development is a fascinating journey that has evolved over 2,000 years of innovation, experimentation, and exploration. It began with fire-throwing devices and has since progressed into modern rocket science and technology. The initial pioneers affixed rudimentary rockets to their wooden glider aircraft, signifying the birth of rocket airplanes. The development of large-scale rocket technology and wartime advances in electronics in the mid-20th century led to proposals for satellites and the subsequent development of satellite technology (Evans et al., 2011). This period also saw the emergence of electric propulsion, which has evolved over almost a full century, epitomizing the progress of the field from its inception as the dream realm of a few visionaries to its transformation into the concern of large corporations (Choueiri, 2004). Rocket technology, first created for military purposes, has served as an economical platform for scientific research for more than seven years (Christe et al., 2016). The lives of prominent rocket scientists such as Robert Goddard, Wernher von Braun, and Sergei Korolev have played a significant role in shaping early rocket development (Jacob, 2001). The development of low-thrust propulsion systems has also been a crucial aspect of rocket evolution, complementing traditional chemical propulsion systems and enhancing the evolution of future space programs (Keaton, 1987).

The advancement of rocket technology has extended beyond conventional propulsion technologies. The review of "Rocket Science at the Nanoscale" examines the difficulties involved in creating effective micro/nanoscale rockets. It provides a comprehensive analysis of their propulsion characteristics, manufacturing techniques, possible rocket propellants, navigation approaches, practical uses, and future possibilities in the field of nanoscale rocket science and technology (Li et al., 2016). The history of rocket development is a rich tapestry of scientific, technological, and engineering advancements that have shaped the modern world. From its humble beginnings as fire-throwing devices to the development of satellite technology, electric propulsion, and micro/nanoscale rockets, the evolution of rocket technology has been a testament to human ingenuity and innovation.

2. CLASSIFICATION OF ROCKET PROPELLANTS

A propellant is a combination of chemical substances containing fuel and an oxidizer, coupled with specific additives that are required to maintain the combustion process and generate high-pressure hot gases (Hong & Jin, 2005). These gases are then expanded in a nozzle to generate thrust. It should be noted that the primary components of a propellant are the fuel and the oxidizer (Charlery et al., 2015). In basic terms, a fuel is a chemical compound that undergoes a reaction with an oxidizer, resulting in the release of thermal energy (Demirbas, 2008). Fuel is a chemical compound that has the ability to donate electrons when it reacts with an oxidizer. On the other hand, an oxidizer is a chemical compound that receives electrons during a chemical reaction with the fuel. Electronegativity is the inherent characteristic of an atom that enables it to either receive or give out electrons. This trait differentiates between a fuel and an oxidizer. Additives are employed to augment the characteristics of the propellant (Chaalane et al., 2015).

2.1. Types of Rocket Propellants

Rocket propellants can be classified based on various criteria, such as their chemical composition, physical state, and performance characteristics. One common classification system categorizes rocket propellants into four main types: solid propellants, liquid propellants, gel propellants, and hybrid propellants, as shown in Figure 2 (Mishra, 2017).

Solid propellants are composed of a fuel and an oxidizer intimately mixed together in a solid state. These propellants are relatively stable, easy to store, and can be ignited by a simple ignition source (Lin et al., 2020). Solid propellants can be categorized into two main groups: homogeneous and heterogeneous. This classification is based on how the fuel and oxidizer are distributed inside the propellant. Homogeneous propellants have a uniform distribution of fuel and oxidizer, while heterogeneous propellants have distinct regions of fuel and oxidizer (Thakre & Yang, 2010).

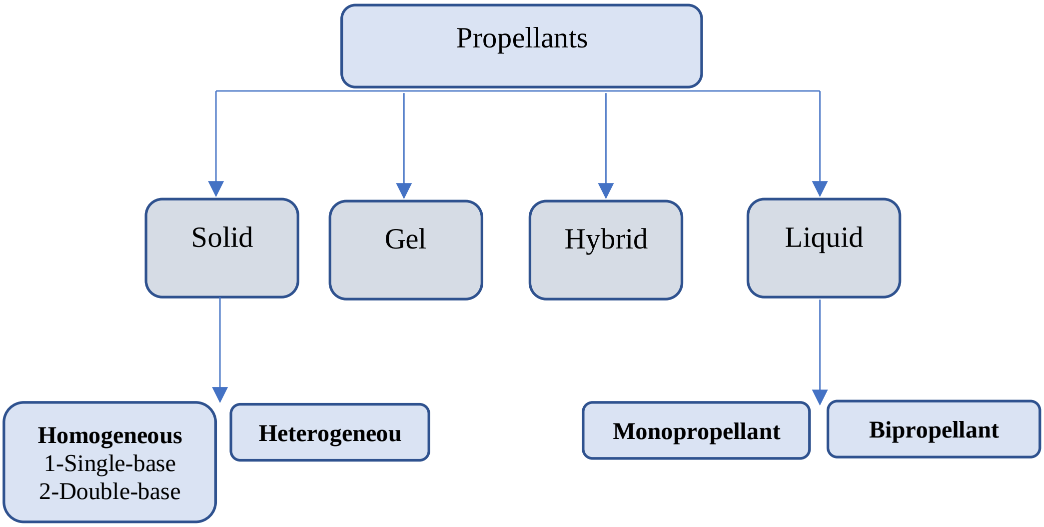

Figure 2. Types of Rocket Propellants

Liquid propellants consist of a fuel and an oxidizer stored separately in liquid form and are mixed and burned in the combustion chamber of the rocket engine. These propellants offer precise control of thrust and can be shut down and restarted as needed (Casiano et al., 2009). This characteristic is essential for the operation of liquid-propellant rocket engines, enabling controlled combustion, variable thrust modulation, and stability. It can be seen in Table 1 comparison between solid and liquid propellants (Mishra, 2017).

Table 1. Differences between solid and liquid propellants

Solid Propellants	Liquid Propellants
Insufficient particular impulse	High specific impulse
Convenient for storage, manipulation, and transportation	Challenging to store, manipulate, and transfer
Designing and developing a solid-propellant rocket engine is straightforward.	Designing and developing a liquid-propellant rocket engine is a complex task.
Testing and calibrating solid-propellant rocket engines can be challenging.	Testing and calibrating a liquid propellant rocket engine is challenging.

Hybrid propellants combine the features of both solid and liquid propellants by using a solid fuel and a liquid oxidizer (Abdous et al., 2022). This configuration offers some of the advantages of both solid and liquid propellants, such as simplicity and controllability.

Gel propellants are known to exhibit characteristics of both solid and liquid propellants. They exhibit the advantages inherent in solid propellants, such as the capability to incorporate energetic elements and achieve higher density, while also offering the benefits associated with liquid propellants, such as increased specific impulse and improved thrust management (Moghaddam et al., 2019). They have solid-like behavior but transition into a liquid state under the influence of an increased shear rate. To increase the particular impulse and solve the issue of sloshing in flight, the liquid fuel of the rocket engine is transformed into a gel by incorporating a higher amount of metal (Mishra, 2017).

2.1.1. Solid Propellants

A typical solid propellant is typically composed of fuel, oxidizer, and additives. Fuel and oxidizer are the main components. Additives are employed in minimal proportions to augment the combustion rate, regulate the manufacturing process, reduce temperature sensitivity, guarantee chemical and physical stability during storage, and enhance mechanical qualities, among other purposes. In general, solid propellants are specifically formulated for various applications, such as sounding rockets, missiles, launch vehicles, and gas generators (Abd Elall & Lin, 2018; Lin et al., 2020).

Solid propellants can be classified into two primary categories: homogeneous and heterogeneous propellants. This classification is based on the physical composition of the fuel and oxidizer within the propellant (Thakre & Yang, 2010). Homogeneous propellants are typically referred to as double-based propellants, while heterogeneous propellants are known as composite modified double-based propellants and composite propellants (W. Wang et al., 2021).

The homogeneous propellants are primarily categorized as single-base and double base. Gun propellants mostly consist of single-base propellants that solely include nitrocellulose (NC) ($[(C_6H_7O_2–(ONO_2)_3]_n$) that plays a crucial role in various types of propellants (L. Chen et al., 2021). Double-base propellants are produced by incorporating an energetic chemical such as nitroglycerin (NG) into NC after plasticization. NG is synthesized by combining glycerin with polyols, which are alcohols that contain multiple hydroxyl groups (Ma et al., 2008). These propellants also contain other materials such as ballistic stabilizers, combustion catalysts, and other additives (Zou et al., 2021). The chemical structure of NG is shown in Figure 3.

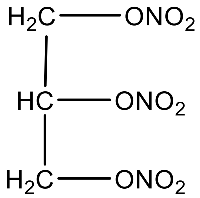

Figure 3. The chemical structure of nitroglycerin

A typical double-base propellant includes some materials such as nitrocellulose (NC) (13.25%N), nitroglycerine (NG), diethyl phthalate ($C_{12}H_{14}O_4$), ethyl centralite ($C_{17}H_{20}N_{2O}$), potassium sulfate (K_2SO_4), carbon black, and candelilla wax (Barrere et al., 1960; Kubota, 2002).

A heterogeneous propellant consists of solid crystalline oxidizers (such as ammonium perchlorate (NH_4ClO_4)) organic fuel, and metallic fuel powders, all bound together in a plastic (rubber) matrix. Typically, a fuel made of organic plastic binds together the small, crystalline particles of the oxidizer. Heterogeneous propellants include typical ingredients, as seen in Table 2 (Mishra, 2017).

Table 2. Essential components for heterogeneous propellants

Fuel (Binder)	Oxidizer	Plasticizer
PU: Polyurethane PVC: Polyvinyl chloride PBAN: Poly Butyl Acrylo Nitrate PS: Polysulfide HTPB: Hydroxyl terminated polybutadiene CTPB: Carboxyl terminated polybutadiene Metal fuel: Al, Mg, Be, Bor	AP: Ammonium perchlorate AN: Ammonium nitrate KP: Potassium perchlorate NP: Nitronium perchlorate ADN: Ammonium dinitramide RDX: Cyclotrimethylene trinitramine HMX: Cyclotetramethylene tetranitramine	DOP: Dioctyle phthalate DOA: Dioctyl adipate IDP: Isodecyl pelargonete Curing agent TDI:Toluene-2,4-Di-Isocyanate MAPO: Tris(1-(2-methyl) Aziridinyl)phosphine oxide IPDI: Iso-phorone di-isocyanate

2.1.2. Liquid Propellants

Despite their inherent difficulties, liquid-propellant rocket engines are favored over solid-propellant engines because of the additional benefits provided by liquid propellants. They possess a greater specific impulse and have the ability to be quickly adjusted in terms of thrust, turned off, and resumed (Barato et al., 2021; Casiano et al., 2009; Zhu et al., 2015). Liquid propellants comprise liquid fuel, liquid oxidizers, and specific liquid additives.

Various forms of liquid propellants have been developed in the past sixty years. Liquid propellants encompass several substances, such as liquid hydrocarbons, liquid hydrogen, alcohols, and similar compounds. Liquid oxidizers such as liquid oxygen, nitric acid, and liquid fluorine serve as examples. Liquid propellants can be categorized according to the configuration of the fuel and oxidizer, the amount of energy they contain, their ability to ignite, and their ability to be stored (Huang & Huzel, 1992; Mishra, 2017). Liquid propellants can be categorized into two main types: monopropellants and bipropellants.

Liquid monopropellants consist of a single molecule structure that contains both the fuel and oxidizer constituents. Monopropellants, such as hydrogen peroxide (H_2O_2) and hydrazine (N_2H_4), serve as examples. When dealing with liquid bipropellant, the fuel and oxidizer are combined separately in order to generate exothermic reactions. Liquid hydrogen and liquid oxygen are both classified as liquid bipropellants (Mishra, 2017; Taylor, 2009).

2.1.3. Hybrid Propellants

A hybrid rocket propellant is a combination of a solid fuel and a liquid or gaseous oxidizer. It offers advantages such as safety, cost-effectiveness, and environmental friendliness (Shrivastava, 2018). The solid fuel can be composed of materials such as paraffin wax, hydroxyl-terminated polybutadiene (HTPB), or a composite of HTPB and paraffin. The liquid or gaseous oxidizer can be nitrous oxide, liquid oxygen, or hydrogen peroxide (Kaneko et al., 2009; Kawai et al., 2013; Zhukov et al., 2016). The combination of these components results in a propellant with high performance and eco-friendly characteristics (Sun et al., 2016; Wada et al., 2014).

The regression rate, which is the rate at which the solid fuel surface recedes, is an important parameter for hybrid rocket propellants. Studies have been conducted to characterize the regression rate of different fuel combinations, such as HTPB-based propellants, paraffin-based fuels, and low melting temperature thermoplastics (Ismail et al., 2021; Mahottamananda et al., 2020; Sun et al., 2016). These studies aim to understand the combustion behavior and performance of the propellants. The addition of additives, such as high entropy alloys (HEAs), has been proposed to enhance the performance of rocket propellants (Owis, 2011). The use of these additives can potentially increase the specific impulse of the propellant system, leading to improved overall efficiency.

2.1.4 Gel Propellants

Gel rocket propellant is a promising area of research in rocket propulsion systems. Gel propellants possess a distinctive blend of favorable insensitivity and less potential for environmental and health hazards when compared to alternative liquid and solid rocket propellants (Ciezki & Naumann, 2016). They are renowned for their high specific impulse, low sensitivity, and low vulnerability, as well as their capacity to regulate thrust, which makes them an appealing choice for rocket propulsion systems (Teipel & Forter-Barth, 2005). Gel propellants have been studied for their rheological properties, thixotropic performance, and the potential introduction of nano-accelerant powders to enhance overall performance (Chen et al., 2017; Jyoti & Baek, 2014). Moreover, extensive research has been carried out to investigate the composition and analyze the flow characteristics of gel propellants for diverse applications in rocket propulsion systems (Jyoti & Baek, 2014). Gel propellants have been investigated as a novel, high-energy, environmentally friendly, and non-toxic propellant, showing promising potential for use in the aerospace sector (Wang et al., 2020).

In addition, efforts have been made to create more environmentally friendly rocket propellants. These propellants are composed of recycled PET-based polyurethanes serving as the binder, phase-stabilized ammonium nitrate acting as the environmentally friendly oxidizer, energetic plasticizers, aluminum functioning as the fuel, and Fe_2O_3 serving as the catalyst (Dirloman et al., 2021). Gel propellants have also been tested as oxidizers in catalyst ignited hybrid thrusters, demonstrating the feasibility of using gel propellants in rocket systems (Huh et al., 2018). Furthermore, gelled propellants possess the capability to supplant traditional solid and liquid fuels by amalgamating the distinct benefits of both systems while simultaneously disregarding the majority of their drawbacks (Arnold & Anderson, 2010).

3. ESSENTIAL PROPERTIES OF ROCKET PROPELLANTS

Each type of chemical propellant, which is based on a physical entity, possesses unique and desirable qualities that contribute to high-level performance. Every propellant must possess superior energetic qualities to guarantee a higher rate of heat release, together with a high combustion temperature, unique velocity, and particular impulse. In addition, the propellant must possess exceptional ballistic characteristics, including low density, heightened flammability, consistent performance, and minimal combustion instability (Barrere et al., 1960; Mishra, 2017; Wimpress, 1950). The utilization of propellants with low density necessitates the use of larger storage tanks, thereby boosting the bulk of the launch vehicle. Desirable qualities of propellants include properties such as storage stability, reduced risk of explosion, smokeless exhaust, affordability, and ease of processing. The typical desirable characteristics of chemical propellants are as follows: (Mishra, 2017; Razdan & Kuo, 1983; Sutton & Biblarz, 2001)

1. The propellant must possess a high chemical energy release in order to achieve a greater combustion temperature, resulting in a higher unique velocity C*.
2. The combustion product can have a low molecular weight, resulting in a high exhaust velocity (V_e) and therefore a high specific impulse (I_{sp}).
3. It possesses a high density, allowing for the storage of a significant amount of chemical energy in a little volume, enabling a compact design.
4. Highly combustible even in low-pressure environments.
5. Exhibiting long-term physical and chemical stability.
6. Free from smoke and devoid of toxins.
7. Simple and costly to produce and manage during use.
8. Widely accessible and affordable.
9. Exhibits reduced susceptibility to explosive risks.
10. Minimal emission level.

4. NEW DEVELOPMENTS IN ROCKET PROPELLANTS

The development of rocket fuel has seen significant advancements in recent years, with a focus on some subjects such as sustainability, cost-effectiveness, performance, and environmental sensitivity.

One significant advancement is the exploration of sodium-water reaction (SWR) as a propellant, which offers excellent energetic properties, environmental friendliness, and cost-effectiveness. This novel strategy seeks to substitute existing costly and harmful substances with a sustainable, inexpensive renewable fuel, thereby promoting a more environmentally friendly energy source for the field of rocket research (Guerrero et al., 2018).

The use of 98% hydrogen peroxide as an oxidizer in hybrid rocket propulsion technology has been a subject of development, emphasizing the green and storable nature of the technology (Okninski et al., 2021). Furthermore, the application of energetic materials for solid composite propellants in defense rocket development highlights the continuous renewal and enhancement of propellants in the defense sector (Runtu et al., 2023).

In the pursuit of sustainable alternatives, the research of hydrogen and fuel cell technology in the aircraft and aerospace industries has been conducted to address the environmental impact of traditional liquid fossil fuels (Baroutaji et al., 2019). Moreover, the utilization of rocket fuel waste, such as the Furfuryl Alcohol-Fuming Nitric Acid Hypergolic Pair, has been explored, providing a practical approach to processing disposed rocket fuels and contributing to materials science (Chalmpes et al., 2020).

The development of new, green, and cost-effective fuel blends, such as ionic liquid and biofuel blends, has been reported, showcasing efforts to create environmentally friendly propulsion solutions (Bhosale et al., 2016). Additionally, the use of "green" propellants has been a significant focus in rocket propulsion research and development, emphasizing the importance of environmentally friendly propellants (Surmacz, 2016).

Advancements in the burning rate of solid rocket propellants and the development trends of liquid hydrogen-fueled rocket engines have been subjects of experimental investigation and study, highlighting the continuous efforts to enhance rocket fuel performance and efficiency (Ha et al., 2022; Yaman et al., 2014).

An important progress in rocket propulsion technology is the creation of high-performance hybrid rocket engines that use LOx and paraffin-based fuels as propellants. This innovation demonstrates the continuous efforts to enhance the efficiency and performance of rocket propulsion systems through the utilization of advanced fuel combinations (Kobald et al., 2019).

The utilization of dual-fuel sugar-based solid rocket propellants has been investigated to improve ballistic and rocket motor efficiency, highlighting the ongoing exploration of alternative propellant formulations to achieve higher energy output and performance (Adeniyi et al., 2021).

The evaluation of the mechanical characteristics of aged composite propellants by non-destructive indentation techniques in solid propellant rocket motors highlights the emphasis on guaranteeing the long-term structural integrity and constancy of rocket propellants (Bihari et al., 2022).

5. CONCLUSION

In summary, the advancements in rocket propellants and fuels encompass a wide range of innovative approaches, including the exploration of new fuel sources and sustainable propellants, the development of high-performance engines, the investigation of alternative propellant formulations, green propulsion technologies, environmental friendliness, and the enhancement of injection schemes to enhance performance and structural integrity. These advancements collectively contribute to the continuous improvement of rocket propulsion systems in terms of efficiency, performance, and environmental sustainability.

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CHAPTER 4

EFFECT OF TOOL ROTATION SPEED ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF THE FRICTION STIR LAP WELDED 7075-T651 AL ALLOY

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1. INTRODUCTION

An ongoing effort has been made recently to lighten the weight of a variety of transportation systems with the goal of increasing fuel efficiency and hence reducing energy consumption. There has been an increase in the use of lighter materials, especially aluminum alloys, in the production of cars, aircraft, railcars, ships, and other items utilized in the transportation industry (Miyagawa et al., 2009). Aluminum alloys could be utilized in place of steel sheets in the manufacturing of structural bodies to reduce weight due to their unique characteristics such as good strength-weight ratio (Lee et al., 2007). As aluminum alloys have high thermal and electrical conductivities and it is necessary to shield the weld pool with gas and remove oxide layers either before or during the welding operation, welding them is challenging through fusion welding methods (Wang and Lee, 2007; Çam and Koçak, 1998). 7075 aluminum alloy is one of the highest-strength aluminum alloys and it possesses a high strength-to-weight ratio and natural aging properties, therefore, many aircraft structural parts are manufactured from this alloy (Feng et al., 2010; Fuller et al., 2010). Welding 7075 aluminum alloy via traditional fusion welding methods is very challenging as it comprises copper leading to the formation of damaging cracks in the weld, and also porosity and lack-of-fusion defects occur (Fu et al., 2011; Rajakumar et al., 2011; Gupta et al., 2006). Consequently, it is not possible to achieve high-strength joints in the welding 7075 aluminum alloy by fusion welding methods. In the manufacturing of fuselage panels of aircraft, 7075 aluminum alloy stringers are lap-joined to 2024 aluminum alloy skins with rivets (Christner et al., 2003; Dracup and Dracup, 1999). Friction stir welding (FSW) which is a solid-state joining method has emerged as an effective technique in recent years for combining a variety of aluminum alloys, including the 2XXX, 5XXX, 6XXX, and 7XXX series and also other metals like steel, copper, and magnesium alloy (Chen et al. 2006). In the FSW, materials do not melt (Thomas et al., 1991), thus cracks and porosity problems usually formed in the fusion welding significantly reduce in the FSW weld resulting in the weld with high mechanical properties and unweldable 7XXX series aluminum alloys like 7075 can be welded via the FSW (Jata et al., 2000; Nandan et al., 2008; Rhodes et al. 1997). Lap joints are used in the majority of aircraft and aerospace sheet metal constructions, hence there has been an increase in interest in using FSW technology to join Al alloys in lap configuration in recent years. Given that many high-strength aluminum alloys have low fusion weldability, these joints are often formed by riveting (Mishra and Ma, 2005). When combining Al alloys in a lap arrangement, using FSW rather than riveting can result in considerable weight and cost reductions, as well as increased mechanical performance and less complicated fabrication (Babu et al. (2012). Babu et al. (2012) studied FSLW and riveting AA2014 Al alloy sheets. They obtained that the lap shear strength of FSLW welds is significantly higher than that of riveted joints. FSW is considered a strong and effective welding method, especially for light alloys that are hard to be welded. However, FSW has been often preferred for welding sheets in butt joining configurations. There are many parts joined in the lap joining arrangement. Therefore, it is also very important utilizing FSW for lap combining sheet materials. As a result, very important 7075 aluminum alloy plates were lap combined with investigating one of the most vital FSW variables of tool rotation speed on joint quality.

2. MATERIALS AND METHODS

In this study, pairs of 2 mm thick, 100 mm wide and 100 mm long 7075-T651 aluminum (Al) alloy sheets were welded by friction stir lap welding (FSLW). Chemical and mechanical characteristics for 7075-T651 Al alloy are provided in Table 1 and 2, respectively. FSLW welds were fabricated at three different welding tool rotation speeds (750, 1050 and 1350 rpm (revolution per minute)) under the conditions of the tool fixed at a 2-degree tilt angle clockwise, 3.5 mm plunging depth and 22 mm/min fade rate as shown in Figure 1. The welding tool utilized in the production of FSLW welds was manufactured from H13 steel and it has a 16 mm flat shoulder and a 3.5 mm long cylindrical screw pin with a right screw M5x0.8 mm. Figure 2 demonstrates the produced FSLW welds. The produced FSLW welds were cut to obtain the specimens of tensile shear test, microstructure examination and hardness test. Figure 3 shows tensile shear test samples. Tensile shear testing of samples was conducted on a 250 kN SHIMADZU tensile tester at a 1.5 mm/min constant speed as seen Figure 3. For microstructure analysis, the cross-section of the welds was ground, polished, and then etched using Keller’s reagent. After that, images of the microstructures were attained by AOB inverse metal optical microscope. Hardness of the welds was measured from their etched cross-sections by THV-

1D Vickers hardness devise. Fracture area examination was carried out by Scanning Electron Microscope (SEM) devise. The advancing side is the side where the tool rotation direction and the welding direction are the same, whereas the retreating side is the side where the tool rotation direction and the welding direction are the opposite (Yang et al., 2011).

Table 1. 7075-T651 Chemical composition

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Weight (%)	0.4	0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	5.1-6.1	0.2	Rest

Table 2. 7075-T651 Mechanical features

Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
540	460	11.5

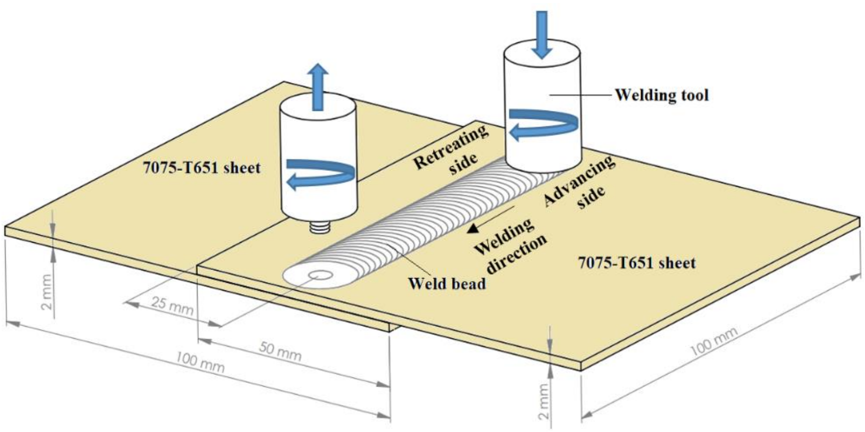

Figure 1. Schematic representation of the FSLW experiment

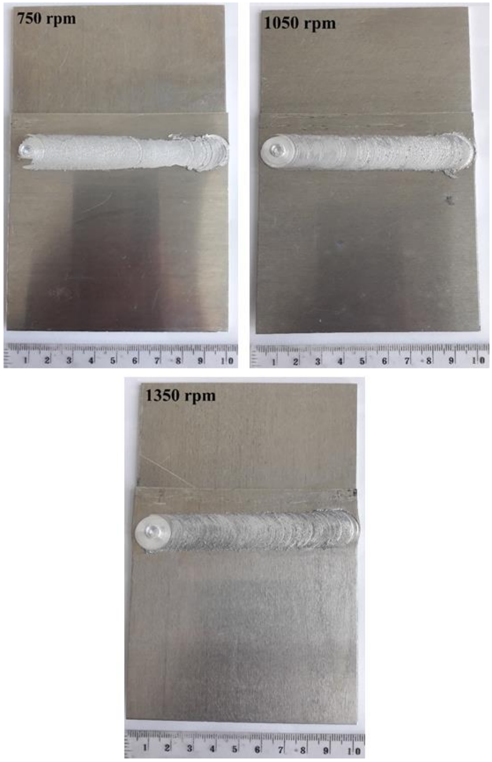

Figure 2. FSLW welds made at different tool rotation speeds

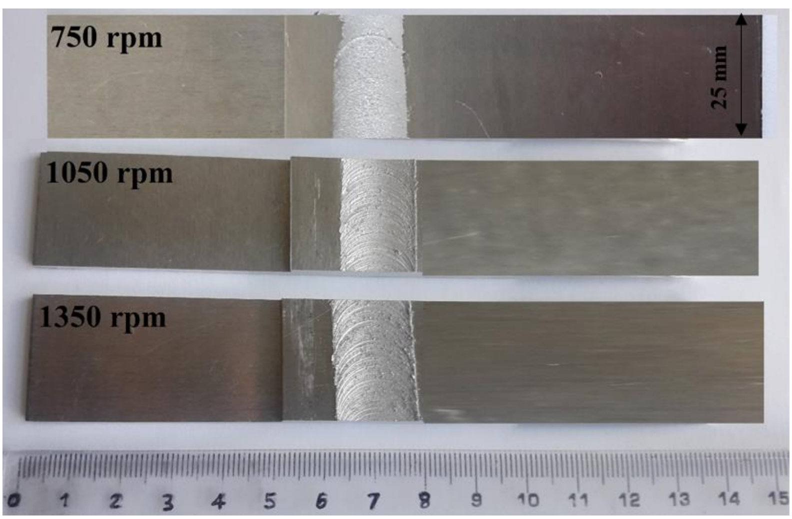

Figure 3. Weld specimens for the tensile shear test

Figure 4. Photo of tensile test

3. RESULTS AND DISCUSSION

Macro cross sections of the welds are given in Figure 5. No flaws like voids, cavities, and tunnels are observed.

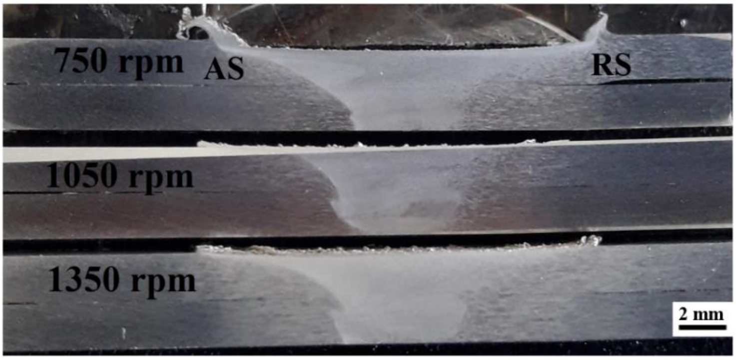

Figure 5. Macro view of cross sections of the welds

Figure 6 illustrates the microstures of the welds fabricated at different rotation speeds. It can be seen that the microstructure of the weld made at 1350 rpm is more uniform, denser, and composed of the smallest grains compared to other microstructures. It is clear that the size of the grains in the weld microstructure gradually became smaller with increasing rotation speed.

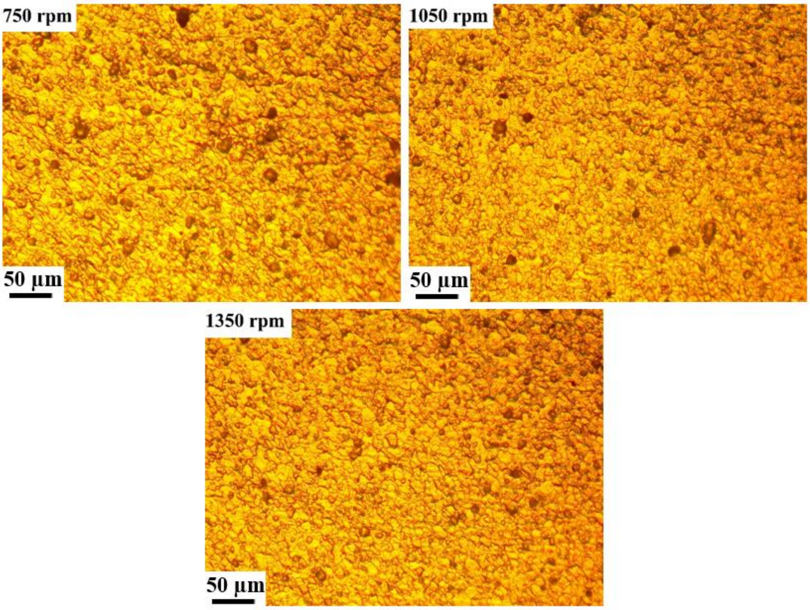

Figure 6. Microstures of the welds made at 750, 950 and 1350 rpm

Figure 7 indicates the interface orientation of the sheets in the welds as a result of the tool plunging action. It is seen that as the tool rotation speed increases, the interface becomes more curved and moves further away from the weld region (WR). The interface of the weld made at 750 rpm bent slightly down and entered the WR. This interface entering the WR could be the suitable place for crack formation and propagation and this can lower weld strength when the weld is under load.

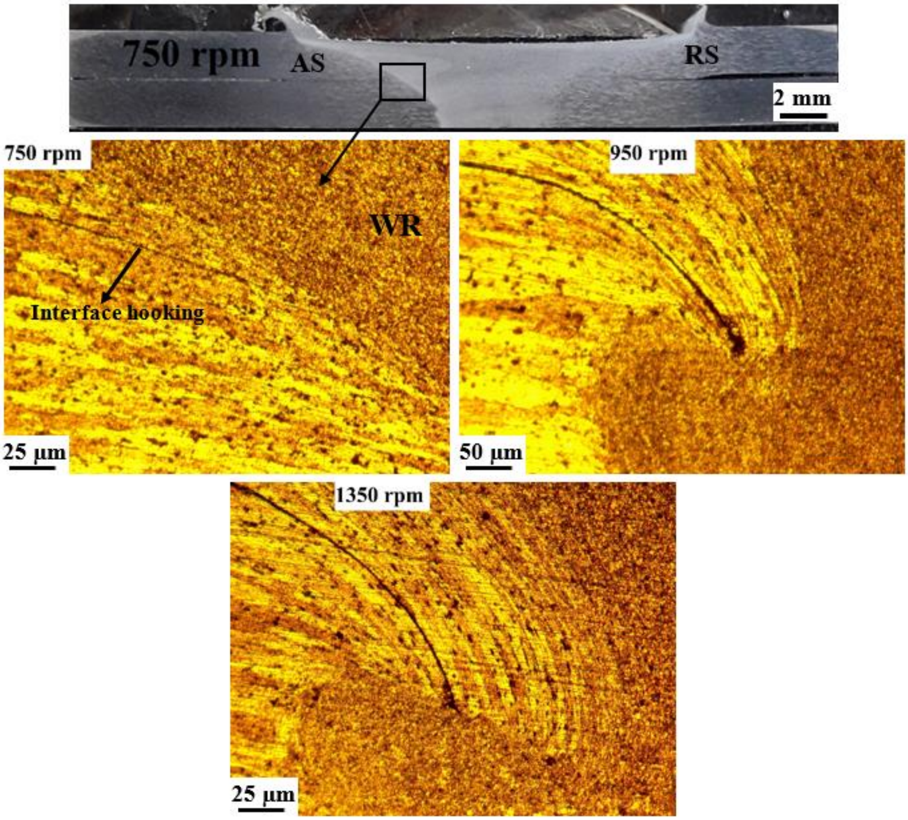

Figure 7. Images taken from the advance side show the orientation of the interface of the sheet

Figure 8 demonstrates the images taken from the centers of the welds. It can be seen that kissing bond imperfection (incompletely joined lines coming from the interface line of the parts at the retreating side) at the centers of the welds. This defect was not detected in the weld made via 1350 rpm.

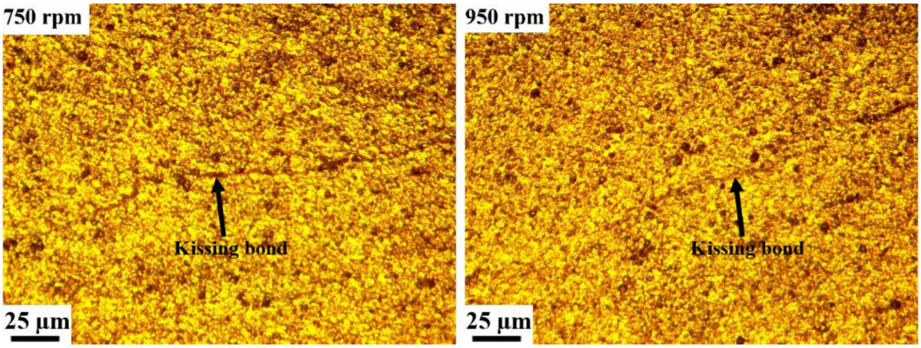

Figure 8. Kissing bond imperfection found in the centers of the welds

The measured Vickers hardness values for BM, HAZ, TMAZ and WR on the weld of 1350 rpm are presented in Figure 9. The highest hardness values were measured in the WR apart from BM. The WR was harder because it experienced like cold-hardening, intensive heat, plastic deformation, and recrystallization and thus contained much smaller grains in its microstructure. The HAZ was the softest as it had large and round grains because of only exposure to the heat.

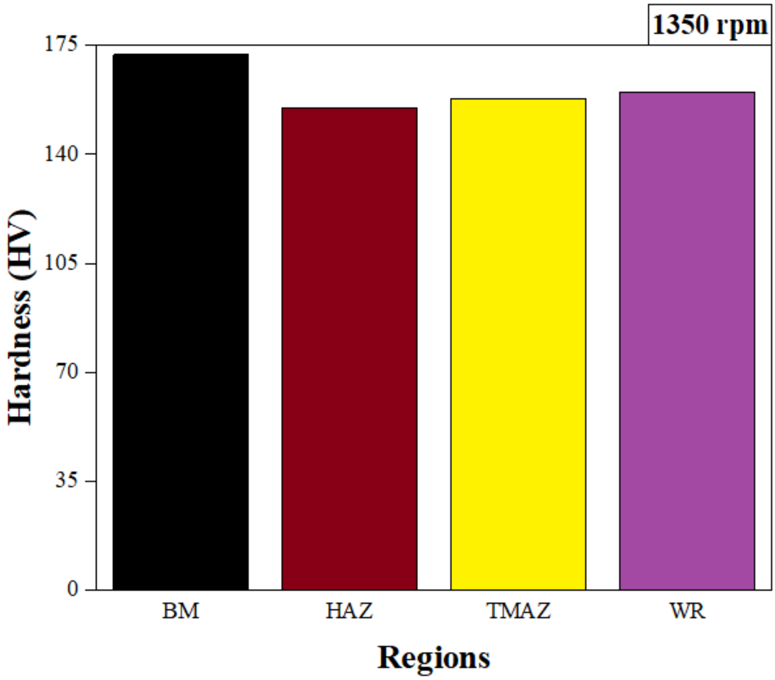

Figure 9. Hardness of BM and different zones on the weld made at 1350 rpm

The tensile shear load-elongation curves of the welds are given in Figure 10. It is clear that the weld made at 1350 rpm is the strongest, while the one produced at 750 rpm is the weakest. Also, The weld strength and elongation increased with raising the tool's rotational speedFrom these tensile test results, it is clear that 750 rpm is not suitable for mixing the materials of the sheets and thus achieving a stronger joint. 1350 rpm seems to be a more suitable value for softening and mixing the materials and thus creating a strong connection. From the microstructures of the welds in Figure 6, it can be seen that the microstructure of the 1350 rpm weld is finer-grained and more uniform. It can also be seen from the fracture photos of the welds in Figure 11 that 1350 rpm weld area resisted the tensile force more and therefore showed more elongation. Additionally, the kissing bond imperfection was not seen in the weld of 1350 rpm. However, this defect was observed in the welds of 750 and 1050 rpm as shown in Figure 8. Tuccia et al. (2021) studied FSLW of 2198 and 6082 dissimilar Al alloys using different tool rotation speeds (1200, 1500 and 180 rpm). They produced the strongest weld at 1500 rpm.

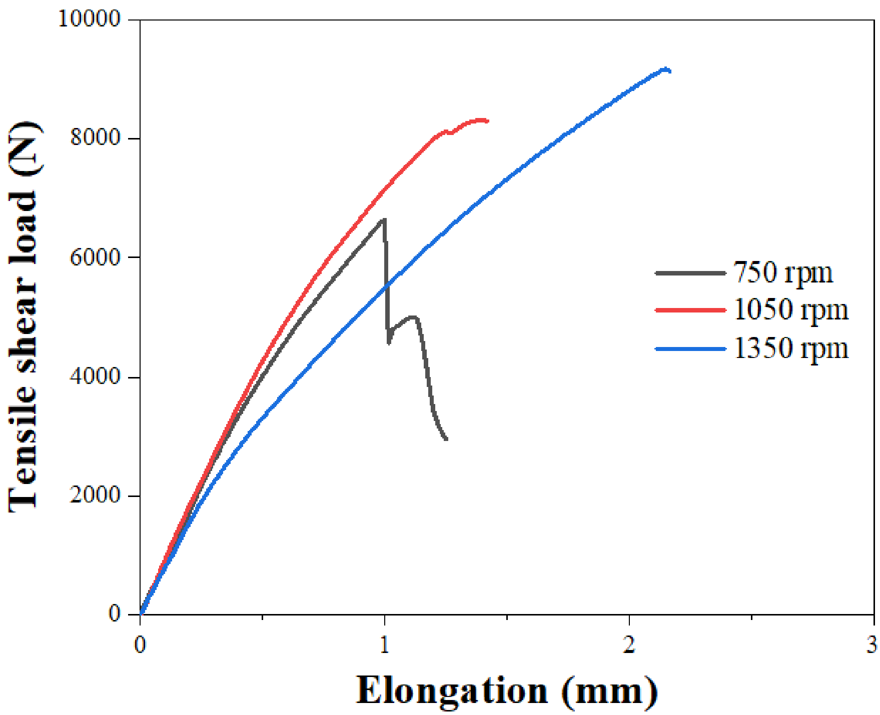

Figure 10. Tensile shear test result of the joints

Figure 11 shows the view of the fractured weld samples after being exposed to the tensile test. All the samples broke from the bottom sheet at the RS and exhibited a tensile-type fracture. For all welds, the fracture started from the interface of the sheets at RS and progressed to the weld area, and the rupture occurred in the weakest weld region. Since the generated heat for softening, stirring, and mixing materials being welded is insufficient at 750 rpm, a small weld area was formed due to the materials not being mixed well, and as a result, it can be seen that it breaks almost straight. On the other hand, since the materials were mixed better at 1350 rpm, the produced weld had a larger joining area than other welds and therefore, showed more resistance to tensile force and broke with more elongation.

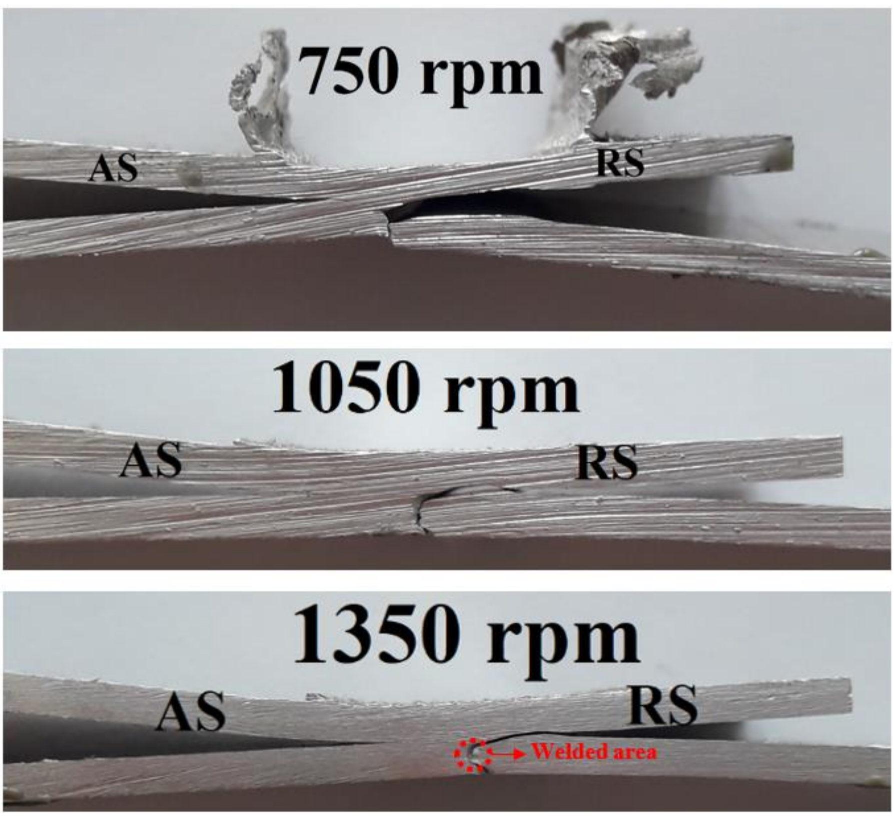

Figure 11. Fractured weld samples after tensile testing

Figure 12 indicates the fracture surface SEM image taken from the weld made at 1350 rpm. It can be seen that there are many large and small sizes of dimples. The formation of dimples is an indication of ductile and quality weld formation.

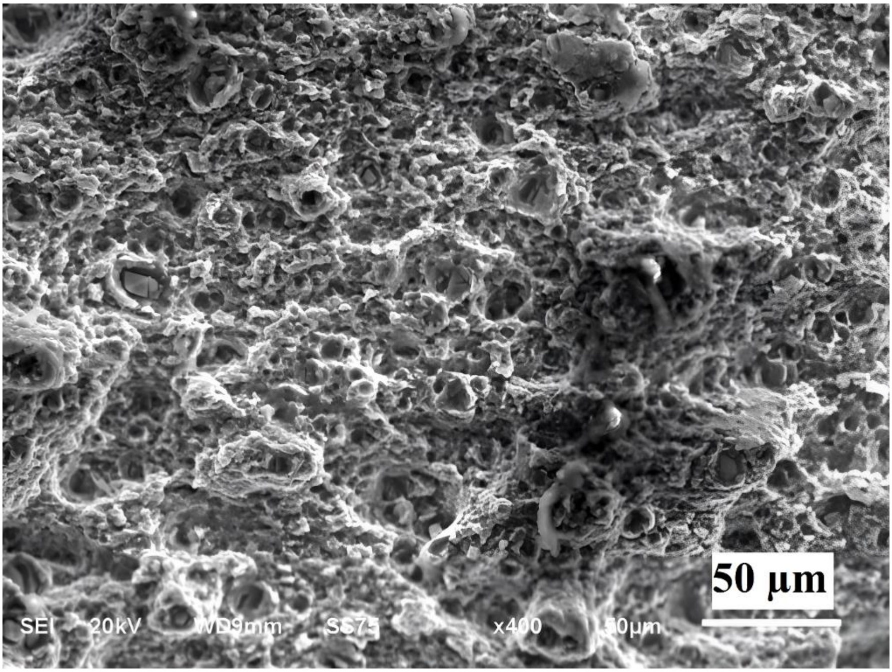

Figure 12. SEM photo of the weld fracture zone

4. CONCLUSIONS

A pair of 2mm thick 7075-T651 Al alloy sheets were successfully lap-joined by the FSW using a tool with a threaded cylindrical pin and applying tool rotation speeds ranging between 750 and 1350 rpm. It has been seen that rotation speed has a significant impact on the weld quality. When the tool rotational speed was increased, a stronger weld formed, and the best weld was created at the highest rotation speed of 1350 rpm. The weld produced at 1350 rpm showed better strength thanks to having a more uniform, denser microstructure and a hook further moving away from the interface joining area as well as not having a kissing bond flaw at the weld center. After the tensile shear tests, it was seen that there is a ductile fracture from the weld fracture surface of the weld made at 1350 rpm.

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CHAPTER 5

ADVANCED NANOTECHNOLOGY COATINGS USED IN THE AEROSPACE INDUSTRY

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1. INTRODUCTION

The regular layer formed by applying another material to a material's surface in a single or several thin layers is called coating (Sadiku, Agboola, Ibrahim, Olumambi, & Avabaram, 2019). A wide variety of coatings are available with many different properties, consisting of many different components such as pigments, binders, various additives and fillers. Usually, coating is applied to improve the mechanical, chemical, thermal, optical, electrical and magnetic properties of the material. Coatings are additionally employed to enhance the substrate's surface qualities, such as resistance to corrosion, wear, and scratches.

Nanotechnology involves methods that offer the ability to manipulate materials at the atomic or molecular level. It is frequently encountered as a technological advance that takes advantage of the superior properties of materials at the molecular level. The application of nanotechnology in protective coating has gained momentum recently. Because of their superior qualities, which are some absent from traditional coatings, nanostructured coatings have a significant deal of potential for a wide range of applications. Thanks to studies on the benefits of nanoscale materials-such as their distinctive thermal, electrical, and opto-magnetic properties-structural and functional qualities of these materials can be improved for space and aircraft applications.

Nano-coating applications are defined as an ultra-thin layer or chemical structure formed in nanometer size on the surface. Various nanotechnological techniques, including chemical vapor deposition (CVD), atomic layer deposition (ALD), physical vapor deposition (PVD), electrospray, and electrospinning, are employed for nano-coating applications. It is possible to alter the characteristics of traditional coating components like pigments and binders by adding nanoscale materials functionalized with various molecules like nanotubes, nanofibers, nanoparticles, and nanosized graphites. In order to change the properties of a surface or material, this process can be carried out with procedures designed according to the desired parameters. The resulting nano-coating can provide properties such as resistance to scratches, pressure, extreme heat, hardness, and resistance to mold and bacteria. Thus, a highly durable coating product with high performance properties can be developed. Several industries, including electronics and optics, food and packaging, aerospace, marine coatings, construction, and civil engineering, automotive, oil and gas, and biomedical, have recently adopted nano-coatings. Nanotechnology coating advancements have strengthened and increased the value of the aerospace industries. Anti-corrosion nano coatings have the potential to drastically lower high maintenance costs in the aviation sector, particularly in the military aviation sector. Moreover, nanotechnology coatings processes have a wide range of uses in the aerospace and defence sectors, including enhancing the performance and longevity of different parts and creating long-lasting coatings to reduce friction and corrosion and enhance surface quality.

Advanced Nanotechnological coatings are high-tech surface treatments used in the aerospace industry to increase the performance, durability, and functionality of materials. While these coatings increase the resistance of materials to various environmental factors such as wear, corrosion, heat, radiation and impact, they also provide light weight and cost savings. Nanotechnological coatings used in the aviation and space industry have many application areas, including resistant to extreme hot and cold climate conditions on the surfaces of aircraft, preventing wear of engine parts and radar absorbing coatings (Taylor & Sieradzki, 2003). Much research is currently ongoing on other specific uses of nanoparticles and nanocomposites in the aerospace industry. These researchers include fire retardation, microwave absorbers, sensors for detection and actuation, electrostatic discharge (ESD) dissipation, privacy, and security. In order to develop the ultimate materials, advanced nanotechnological coatings-such as hydrophobic, protective, cooling, and friction-reducing surface coatings-keep pushing the limits of their application in industry. These new technological advances can offer more environmentally friendly, cheaper and safer recommendations. Like traditional coatings, nanotechnological coatings are generally composite materials consisting of binders, additives, fillers and pigments. Composite materials are formed by combining at least two different material classes with different chemical and physical properties. Binding phase materials in nanotechnological coatings may include polymer-based materials such as acrylic, silicone, polyurethane, epoxy and silicates. Usually, oxides like ZnO, TiO_2, Y_2O_3, and ZrO_2 are commonly utilized as pigment materials (Hoły, Tighe, & Semprimoschnig, 2018). When these two different materials, called matrix and reinforcement, are combined, they form a new material that often has superior properties than its constituent parts. Because of their appealing qualities such as their high strength to weight ratio, low weight, resistance to chemicals and weather, flexible design, and inexpensive installation composite materials have completely changed the aviation industry. Among the nanoparticles researched for nanocomposites: Zinc oxide (ZnO), silicon dioxide (SiO_2), Titanium dioxide (TiO_2), used to increase the wear, corrosion and heat resistance of metal or composite materials. It can also be used in sensor or actuator applications due to its optical and piezoelectric properties. Titanium dioxide nanoparticles are preferred as self-cleaning or non-fouling coatings due to their hydrophilic properties. Metal or composite materials can have their electrical and thermal conductivity improved by using graphene. The mechanical and chemical characteristics of nanotechnological coatings allow them to also be employed as a reinforcing barrier as well. The use of nanotechnological coating can also enable crack healing in the coating. They are preferred to increase the high temperature performance and strength of the self-healing material. Additionally, nanocomposites are used as radar absorbing materials (RAM) in the production of stealth aircraft.

"Stealth Technology" (ST) is used to make ships, aircraft, missiles, submarines and satellites invisible to radar, infrared and sonar other detection (Ahmad vd., 2019). Another name for it is low observable technology. The first coating for stealth application was developed in Germany during World War II on submarines to absorb microwaves from radar. Although no aircraft is completely imperceptible to radar, aircraft coated with nanotechnology pose challenges to the detection and tracking capabilities of traditional radar. On external surfaces, radar absorbing material (RAM) is essentially painted. These paints are made of materials with a magnetic base and dielectric elements like carbon. RAM makes the object appear smaller by lowering the radar cross section. Stealth technology (ST) lowers the amount of electromagnetic waves that are reflected into the radar system by combining surface geometry and RAM composition. The RAM derived carbon-based composite materials offer excellent design and property control flexibility. Carbon fibers, graphene, carbon nanotubes (CNTs), and carbon black particles are all used in composites to modify the material's wave absorption characteristics.

As a result, advanced nanotechnological applications continue to shape the future of the aviation and space industries. This book chapter, advanced nanotechnological coatings and approaches to stealth technology used in the aviation industry are mentioned.

2. RADAR CROSS SECTION (RCS)

The radar cross-sectional area (RCS) is called the degree of a target's detectability by a radar system. RCS is not only the percentage of absorbed and reflected energy but is also considered one of the properties of the target's dimensions, appearance and material that gives it its composition. The targets that are too small compared to the incoming radiation wavelength cause the Rayleigh scattering, while larger targets exhibit optical scattering which has diffraction and specular scattering. On the other hand, Mie scattering occurs when the wavelength and object size are similar. These are elastic scatterings in which the wavelength and energy of the scattered radiation are preserved. It is possible reducing the Radar cross section with four basic methods. These methods are shaping, passive loading, active loading and distributed loading. The shaping procedure is the main strategy used to achieve the lowest rate's backward scattering of signal. Although shaping seems crucial, it redirect radiation through specular reflection, so rising the risk which is bistatic radar detection (Saville, 2005). Active materials detect from radiation then, it emits signals reverse phase and same amplitude to block signal on the other hand, passive materials are arranged for change surface impedance to abolish the scattered signal. Objects which have higher-level of RCS, can be easily detected by radar systems. By altering the characteristics of signal or target, this situation can be overcome. Target characteristics can be improved by making some adjustments, such as modifying the target's size, structural material, which impacts the reflection rate (for instance, metal structures exhibit high reflectivity and lead to high RCS), and shape, which is invisible to radar systems and does not reflect radar signals. On the other hand, the signal characteristics are influenced by the incidence, reflection, and frequency values: Depending on the location from the radar source and the subject structure, the angle of incidence may vary. The angle at which the reflected wave moves away from the target is represented by the reflection angle, which is connected to the angle of incidence. Also, excitation of the incoming wave's dipole moments causes low-frequency scattering, which is related to the volume of the target. Moreover, currents on the surface of the target are activated following incoming waves at high frequencies, and their response depends on the structure of the target (Ruiz-Perez et al., 2022; Saville, 2005).

3. RADAR-ABSORBING MATERIALS (RAM)

Radar, that first emerged around the World War II later continues to develop today, has become significant part of air combat. The main reason for this situation is that radar has the ability to detect aircraft and other radar reflecting materials from long distances, regardless of weather conditions, day or night. With radar, detailed and precise information about the target object can be obtained. As shown in Figure 1, radar not only produces electromagnetic waves, but also collects the waves reflected back after the generated electromagnetic waves hit an object (Kim et al., 2023). Thus, in addition to object detection with radar, many more sensitive information such as target object distance, speed, angular position, direction, size and shape are obtained by processing the reflected waves.

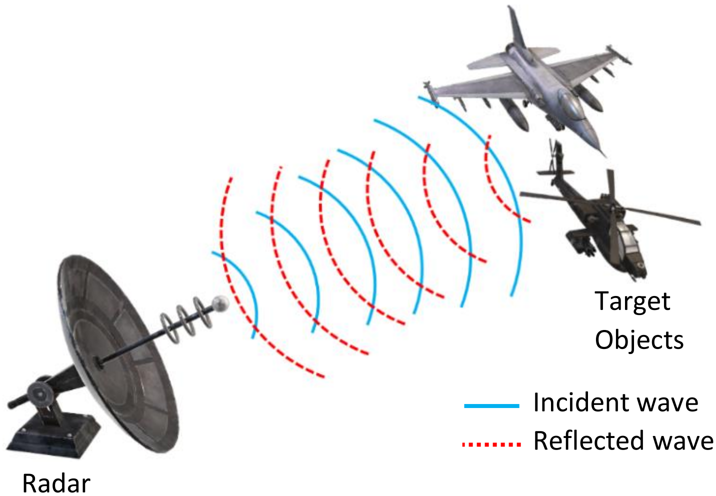

Figure 1. Basic radar system working mechanism (Ruiz-Perez et al., 2022)

The electromagnetic waves produced by the radar move freely in the air until they match a different object. At the military area, radar-absorbing materials, or RAMs, are special materials to reduce electromagnetic radiation reflected from the target object in order to conceal from the opposing military force and not be detected by the radar. These electromagnetic waves are reflected or absorbed depending with the type of object match. Thanks to these materials, the incoming electromagnetic energy is mostly absorbed, and the electromagnetic radiation reflected from the target object is diminished (Figure 2) (Kim et al., 2023). The properties of RAM's could be optimized by modification their composition, surface geometry and microstructure. Basically, the ideal radar absorbing material essentially should has four features: (a) It should display strong absorption characteristics across a broad frequency band. (b) Particularly for airplanes, the physical structure of the materials has to be light and thin. (c) Through its easy coating layer structure, it is simpler to use and thus should have a short working time. And finally, (d) these materials should need to be suitable cope with the harsh conditions of the environment, including snow, rain, strong winds, and more (Abed & Jawad, 2022).

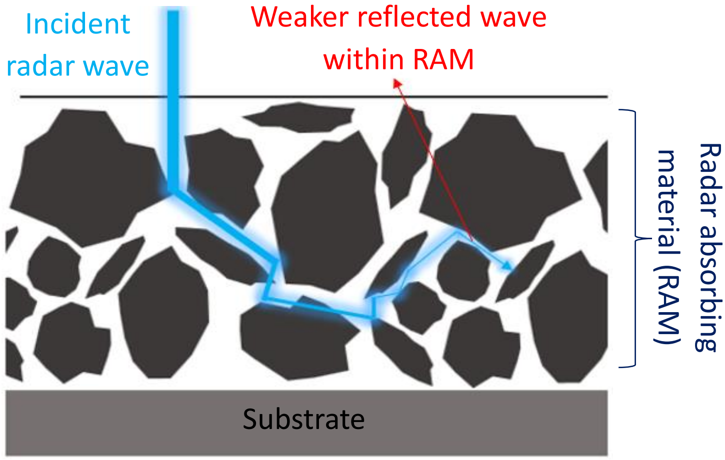

Figure 2. Mechanism of the operation of radar absorbing materials (Abed & Jawad, 2022)

4. RADAR ABSORBING STRUCTURE AND COATINGS AT NANO-SIZED MATERIALS

New materials that may have the ability to absorb microwaves are constantly being researched by material scientists. The majority of the research made on RAM coatings and structures in this time period has been in the field of nanomaterials (Prasad & Wanhill, 2020). Nanostructured RAMs are becoming increasingly popular as they exhibit special properties such as light weight, high strength and impact resistance, as well as greater absorption of microwave radiation. In this study, nanostructured RAMs will be examined basically in three categories. Listed are these categories, in that order: (a) RAMs built from nanocrystals, (b) Nanocomposite RAMs with core–shell structure, (c) RAMs that have a carbon structure (Abed & Jawad, 2022).

4.1. RAMs Built from Nanocrystals

Due to their unique mechanical, optical, and electrical characteristics, nanocrystalline materials are gaining a lot of attention for usage in RAM technology. Because they are also resistant to extreme conditions, these materials are frequently selected in this industry (Dutta, Seehra, Thota, & Kumar, 2008). The quantity of atoms and dangling bonds on the surface of the nanostructure rises when a particle is arranged at the nanoscale. These cause in interfacial polarization and multiple scattering, which considerably enables microwave energy to be absorbed greater amounts and thus the efficacy of nanomaterial has been raising (Wang et al., 2011; Duan & Guan, 2017). Sharma et al. (2008) reported successfully synthesized uniform barium hexaferrite nano crystal which occurs after 4 h annealing from 200 to 1200. As a result of the study, researchers observed diverse size of $BaFe_{18}O_{27}$ nano crystal from 10 to 90 nm. Then, they analysed a few features likes magnetic and refection loss (RL) features in Ku band (12.4 -18.0 GHz). It has been noticed that the uniform morphological growth of RAM nanocrystals during the annealing time resulted in an important rise in RL loss over a wide bandwidth range. The RL loss had been occurred -15.23 dB to -43.65 dB (Sharma, Agarwala, & Agarwala, 2008). In another investigation on nanocrystal RAMs, Wang et al. (2013) have published their report on a hybrid material which made of magnetite (Fe_3O_4) nanocrystals grown on multiwalled carbon nanotubes (MWCNT). In spite of Fe_3O_4 and MWCNT alone exhibit microwave absorbing capacity, it has been realized that a hybrid structure consisting of them shows more significant electromagnetic absorption capacity than qualities on themselves. According to the study, While the critical level absorption ability emerged in the 2–18 GHz frequency range, the study stated that the peak reflection loss was -41.61 dB at 5.5 GHz frequency. As a result, remarkable microwave absorption capability has been shown by nanocrystalline hybrid structures (Wang et al., 2013).

4.2. Nanocomposite RAMs with Core–Shell Structure

RAMs often need to be able to absorb undesirable electromagnetic signals, and in order to do so, they typically require the presence of magnetic and/or electric dipoles that interact with the radiation's electromagnetic fields. Objects which are pure magnetic, or dielectric are inadequate to absorb electromagnetic waves and so they need a few modifications. To rising absorbing capacity, these pure structures can become more functional by adding a layer of additional substances to them. These substances are frequently referred to as nanocomposite RAMs with core–shell structure. Here numerous features, including reflective capacity, can be regulated by changing the dimension and shape of the core or shell regardless of electromagnetic radiation range. The content of the shell in this structure can increase the chemical and thermal stability of cores with various functionalities and also serve as protection for the core material. Core-shell nanocomposites are extremely efficient due to their ideal dielectric and magnetic characteristics. RAMs with core–shell structure have several utilization scenarios, including pharmaceutical delivery mechanisms in healthcare applications, photovoltaic solar energy systems, radar absorption materials, and nanotechnology in electronics. Research on the synthesis and examination of RAMs with core–shell structure microwave absorption characteristics has increased in response to the growing interest in this area in recent years (Y. Wang et al., 2011; Abed & Jawad, 2022). In a study as core-shell nanocomposites investigation, the successful synthesis of $MnFe_2O_4$-TiO_2 nanocomposites which are formed of a core-shell structure was announced by Xiao et al. (2006). At room temperature, $MnFe_2O_4$ composites covered with TiO_2 demonstrated super paramagnetic characteristics. Also, the $MnFe_2O_4$ and $MnFe_2O_4$-TiO_2 composites' complex permittivity and permittivity, which were analysed in the 2-10 GHz microwave frequency range, demonstrated that the composite structures arranged as $MnFe_2O_4$-TiO_2 exhibited better microwave absorption capabilities than pure $MnFe_2O_4$ nanoparticle (Xiao, Liu, & Fu, 2006).

4.3. Stealth Capabilities of Carbonaceous Materials

Stealth technology, also recognized as low observable technology, plays a crucial role in modern military strategies. The utilization of diverse carbon-derived materials, particularly in the development of Radar Absorbing Materials (RAMs), dates back to as early as 1936. The initial RAM patent, used titanium dioxide (TiO_2) for high permittivity (ε) and carbon black (CB) as a lossy resistive material (Hu et al., 2023). Carbon-based materials have attracted significant attention by researchers owing to their distinct properties, which include chemical inertness, stability over a broad temperature range, corrosion resistance, lower density compared to metals, superior thermal and electrical conductivity (R. Sen Zhang & Jiang, 2019). Moreover, carbon materials offer customizable traits such as dielectric loss and surface chemistry, facilitating the attachment of functional groups (Ruiz-Perez et al., 2022). Thanks to their remarkable properties, carbon-based materials find widespread applications in diverse fields, encompassing drug delivery, composite materials, field emission devices, sensors, electronics as well as RAMs and stealth technology (Nasir et al., 2018). Carbon-based materials, including carbon blacks, carbon fibers, carbon nanotubes, and graphene, present themselves as highly promising candidates for incorporation into the industry of stealth technology and the formulation of RAMs. The primary objective of this section is to highlight the recent advancements in carbon-based materials, establishing them as the preeminent choice for the advancement of stealth technology.

4.3.1. Carbon Black (CB)

Carbon black (CB) symbolizes as an amorphous carbon allotrope, primarily composed of small, predominantly spherical carbon atoms bonded in aggregates (M.-J. Wang et al., 2003). Its origin is commonly traced to the combustion of petroleum. The advantageous attributes of CB, such as high conductivity, low density, and notable mechanical strength, have led to its frequent utilization as a reinforcing agent for augmenting the mechanical robustness of RAMs. Furthermore, the electrical characteristics of composite RAMs can be enhanced by meticulously regulating the dispersity, particle size, and density of embedded CB within the composite materials (Kim et al., 2023; Sahoo et al., 2023). The subsequent section will furnish diverse instances of RAMs based on CB, coupled with intricate metallic and polymer composites.

Ibrahim et al. (2020) documented the synthesis of double-layer carbon black/epoxy resin (CB) and $Ni_{0.6}Zn_{0.4}Fe_2O_4$/epoxy resin (F) nanocomposites. Their investigation discusses into the microwave absorbing properties and reflection loss of distinct layer orientations of carbon black and ferrite, as delineated in Table 1. The CB1/F1 orientation exhibited a microwave absorption exceeding 99%, accompanied by a reflection loss of −33.8 Bb, albeit with a limited absorption band-width of 2.7 GHz (Ibrahim et al., 2020). Similarly, Goel detailed the creation of a low-density composite comprising CB and barium hexaferrite ($BaFe_{12}O_{19}$) nanoparticles in varying proportions, employing a ball-milling technique. The composite comprising 80% CB and 20% $BaFe_{12}O_{19}$ demonstrated optimal microwave absorption capabilities, manifesting with low reflection loss (RL) of −56.266 dB at 11.98 GHz, with a thickness of 1.85 mm, as illustrated in Figure 3 (Goel et al., 2021).

Table 1. Presents comprehensive details regarding the double-layer structure of the ferrite/carbon black composite (Ibrahim et al., 2020)

Sample name	Matching layer	Thickness (mm)	Absorbing layer	Thickness (mm)
F1/CB1	Ferrite	1	Carbon black	1
F2/CB1	Ferrite	2	Carbon black	1
CB1/F1	Carbon black	1	Ferrite	1
CB1/F2	Carbon black	1	Ferrite	2

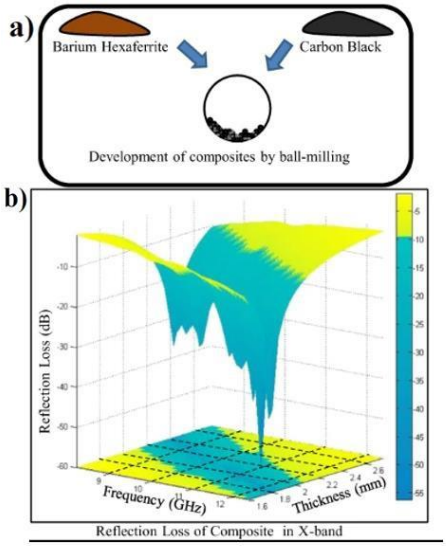

Figure 3. a) Depicts the fabrication technique of the carbon black (CB) Nano powder / barium hexaferrite ($BaFe_{12}O_{19}$) nanoparticles composite. **b)** Presents a 3D representation of the reflection loss of the CB/$BaFe_{12}O_{19}$ composite (80% CB and 20% $BaFe_{12}O_{19}$) (Goel et al., 2021)

Concurrently, Lei et al. (2020) reported the development of a CB/polypropylene composite utilizing fused deposition modeling, incorporating diverse concentrations (wt %) of CB. The resultant composite demonstrates remarkable microwave absorption capabilities and an expansive effective band-width, particularly noteworthy when the CB content is 10%, uniformly distributed throughout the matrix at a layer thickness of 2.8 mm. At this configuration, the highest reflection value attains −62.6 dB at 10.64 GHz. The authors asserted that the exceptional microwave absorption properties predominantly stem from conductive loss, and suitable impedance matching (Lei et al., 2020). As previously emphasized, the incorporation of CB proves advantageous in augmenting microwave absorption characteristics. Consequently, forthcoming investigations should prioritize aspects such as particle size homogeneity, film thickness, dispersion, and surface roughness while optimizing CB concentration.

4.3.2. Carbon Fibers (CF)

Carbon fibers are composed of slender, robust filaments of carbon arranged in a chain-like manner. Characterized by their anisotropic carbon structure with a composition containing at least 92-100 wt % carbon (Frank et al., 2012), these fibers exhibit exceptional properties including thermal stability, electrical conductivity, high specific strength and stiffness, an impressive performance-to-weight ratio, and corrosion resistance. Owing to these remarkable attributes, carbon fibers find extensive applications in diverse fields such as aerospace, mechanical engineering, civil construction, aviation, stealth technology, and the automotive industry (Kim et al., 2023). Further explanation and illustrative examples will be provided.

Singh et al. (2020) detailed the formulation of a nanocomposite by incorporating milled carbon fiber (MCF) and conductive 3D hollow sphere polyaniline (PANI) into an epoxy matrix, resulting in a lightweight material exhibiting superior microwave absorption properties. Varying the MCF/PANI concentration allows for the attainment of optimal microwave absorption. Specifically, the composite containing 4 wt% MCF and 1 wt% PANI, with 1.8 mm in thickness, achieves a peak absorption value of −49.3 dB (99.998% absorption) and an efficient band-width of 1.7 GHz − 10 dB, as depicted in Figure 4. Researchers concluded that the hollow 3D structure enhances impedance matching, substantially amplifying reflection loss through various reflections and the scattering of microwaves within the structure (Singh et al., 2020).

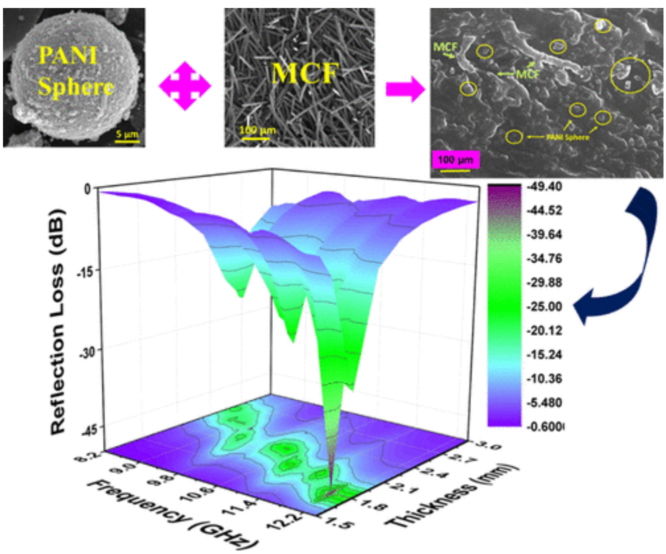

Figure 4. The figure showcases the structural configuration of the MCF/PAIN composite alongside its microwave absorption performance, recorded at -49.3 dB (99.998% absorption) (Singh et al., 2020)

Furthermore, Zhu et al. (2021) successfully synthesized porous carbon nanofibers (PCNF) in conjunction with core-shell cobalt nanoparticles, wherein the CoNPs were dispersed randomly within the porous carbon fiber. The core-shell Co nanoparticles were produced at a significant rate exceeding 50 g/h through a self-developed high-energy ion beam evaporation (HEIBE) process. Concurrently, the Co/porous carbon nanofibers were fabricated using the electrospinning method, as depicted in Figure 5. The Co/PCNF composite exhibits a high reflection loss of −63.69 dB at 5.28 GHz, with a 5.21 mm in thickness, and an absorption band-width (RL ≤ −10.0 dB) spanning 12.92 GHz.

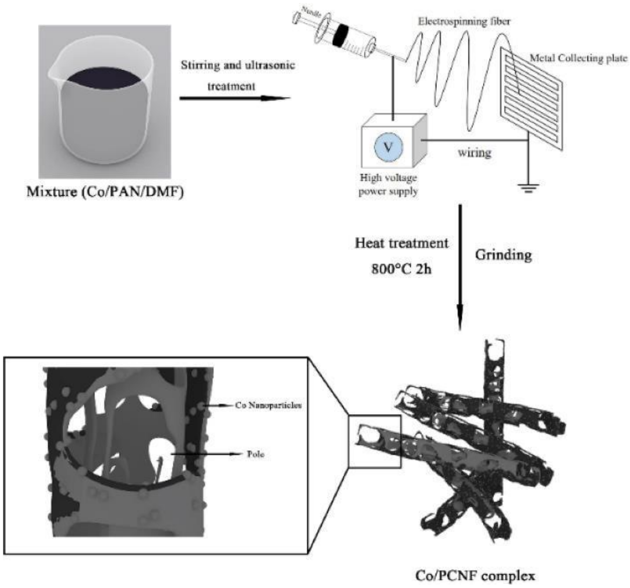

Figure 5. The diagram depicting the fabrication process of Co/PCNF (Zhu et al., 2021)

The authors postulated that the 3D-network structure of cobalt magnetic nanoparticles, coupled with the porous configuration of the carbon fiber, contributes to enhanced dielectric loss, impedance matching, and a high attenuation constant, thereby yielding outstanding microwave absorption properties for Co/CPNFs (Zhu et al., 2021).

4.3.3. Carbon Nanotubes (CNTs)

Carbon nanotubes (CNTs) represent one-dimensional nanomaterials (Kim et al., 2023) with diameters in the order of a few nanometers and lengths extending several centimeters, typically featuring fullerene-like structures sealing both ends (Trojanowicz, 2006). CNTs are categorized into single-wall or multi-walled nanotubes (M. Zhang & Li, 2009). Their unique *sp*^{2}-derived macromolecular structure provides exceptional mechanical strength and toughness, as well as excellent thermal and electrical conductivity. Moreover, CNTs exhibit excellent capabilities in absorbing electromagnetic waves and possess a high aspect ratio. These unique attributes position CNTs as highly promising active components in RAMs and electromagnetic interference (EMI) shielding materials, setting them apart among various nanomaterials (Kolanowska et al., 2018). This section delves into the discussion of various types of CNT-based RAMs, encompassing metal-filled CNTs, metal-coated CNTs, and polymer/CNT composites.

Mo et al. (2019) pioneered the development of a lightweight and porous sponge featuring a core-shell structure composed of carbon nanotubes (CNT) and titanium dioxide (TiO_2) through a straightforward hydrolysis -heat treatment method, as illustrated in Figure 6. This innovative design facilitated precise control over the composition, resulting in tunable dielectric loss properties. Through component optimization, the absorber demonstrated exceptional microwave absorption efficiency, manifesting with low reflection loss of −31.8 dB at 10.35 GHz. Sustaining a reflection loss exceeding −10 dB up to 2.76 GHz for a 2 mm thickness, the absorber's effective microwave absorption (<10 dB) was accomplished by adjusting the thickness within the frequency region between 3.43 - 12.0 GHz. These findings underscore the potential of CNT@TiO_2 sponges as lightweight and efficient materials for microwave absorption (Mo et al., 2019).

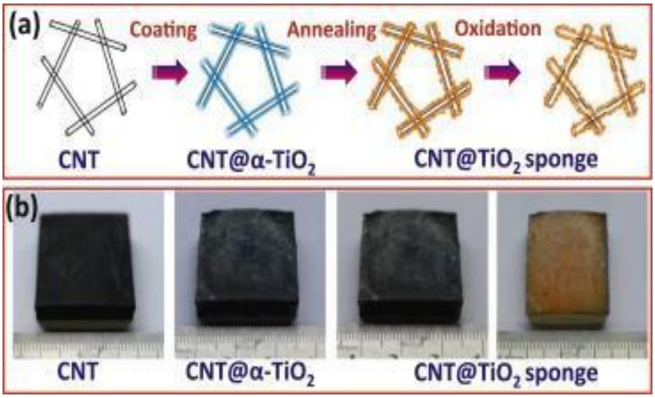

Figure 6. The production steps of the CNT@TiO_2 sponge (Mo et al., 2019)

Wang et al. (2019) provide a study that is focused on enhancing the microwave absorption (MA) performance of carbon nanotubes@polyaniline (CNTs@PANi) hybrids. They achieved this by influencing the interface between CNTs and PANi, increasing the oxidation peeling ratio of CNTs to enhance interface area and defects, thereby improving MA performance. The oxidation treatment caused external graphene nanosheets to peel while remaining attached to CNT inner walls. With increased oxidation time, complete unzipping of CNTs into graphene nanoribbons occurred Figure 7. PANi nanorods were then grown on these treated CNTs, resulting in CNTs@PANi hybrids with uniform PANi nanorod coating on the CNT surface. The CNTs@PANi composite exhibits high microwave absorption (MA) capabilities, achieving a lowest reflection loss of − 45.7 dB at 12.0 GHz with effectual band-width ranges from 10.2 to 14.8 GHz (H. Wang et al., 2019). Zhao et al. (2010) investigated the microwave absorption property of carbon nanotubes (CNTs) incorporated with cobalt (Co) nanoparticles. The filling of Co in CNTs was accomplished through a wet-chemical process. The resulting Co-filled CNT/epoxy composites exhibited reflection loss values below −10 dB within the frequency range of 10.8-14.2 GHz. Furthermore, the introduction of Co nanoparticles in CNT shifted the microwave absorption peak to higher frequencies. This study suggests that Co-filled CNTs hold promise as effective materials for microwave absorption applications (Zhao et al., 2010).

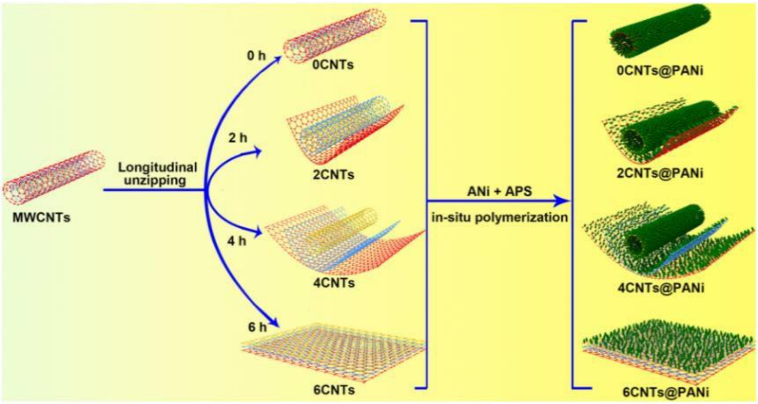

Figure 7. İllustrates the process for preparing op-CNTs@PANi hybrids (H. Wang et al., 2019)

4.3.4. Graphene

Graphene, a single atomic layer derived from graphite (Geim, 2009), exhibits a hexagonally arranged carbon structure (Winson et al., 2019). Geim and Novoselov awarded the Nobel Prize in 2010 for discovery of graphene that has an extraordinary mechanical stiffness, strength, elasticity, and exceptionally high electrical and thermal conductivity. Notably, the adjustable sheet conductivity of graphene is a remarkable feature, allowing fine-tuning across a broad frequency spectrum by altering the electronic Fermi level through electronic or chemical doping. Researchers are particularly intrigued by the potential of incorporating graphene sheets into metamaterial absorbers, especially within the industry of stealth technology, leveraging graphene's unique properties and advantages (Winson et al., 2019).

As an example, Yang et al. (2019) employed a two-step solution-phase technique to manufacture a distinctive three-dimensional (3D) nanocomposite, consisting of 3D graphene and shuttle-shaped ZnO nanoparticles (3DGZ), as depicted in Figure 8. Various proportions of ZnO were systematically explored to assess their impact on microwave absorption properties. The embedded shuttle-shaped ZnO nanoparticles were equally dispersed onto the 3D graphene without aggregation, thereby enhancing interfacial polarization. Notably, the 3DGZ-2 composition exhibited exceptional microwave absorption accomplishment, showcasing a lower reflection loss of −48.05 dB at 11.71 GHz. Additionally, this composite sustained a reflection loss exceeding −10 dB within the frequency range of 12.98 to 17.06 GHz, all at a thickness of 1.5 mm. The authors posit that 3DGZ nanocomposites exhibit promise as extremely efficient, lightweight, thermally stable, and tunable microwave absorbers (Yang et al., 2019).

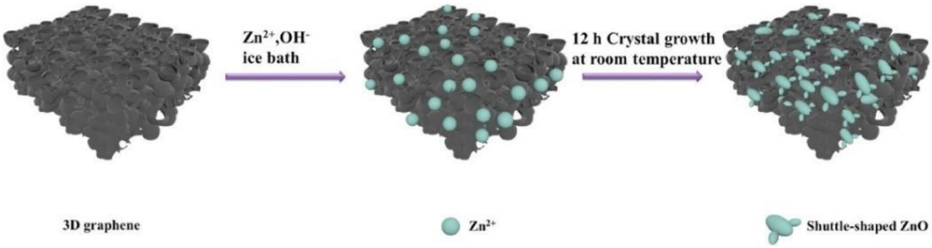

Figure 8. Depicts the synthesis process of 3D graphene/shuttle-shaped ZnO nanocomposites (Yang et al., 2019)

Similarly, Wang et al. (2016) delved into the potential of 2D heterostructure MoS_2/graphene composites as promising materials for microwave absorption (MA). The one-step solvothermal technique employed by the researchers facilitated the production of hybrid 2D MoS_2/graphene composites, where ultrasmall MoS_2 nanosheets were evenly distributed on the graphene surface. The optimized composites demonstrated exceptional MA performance throughout the entire Ku band (12.2-18.0 GHz). Specifically, at 16.1 GHz, a peak reflection loss (RL) of -41.9 dB was observed for a thickness of 2.4 mm. The authors attribute these distinctive features to the high dielectric loss, extensive surface area, and strong multiple scattering effects resulting from the synergistic combination of MoS_2 and graphene (X. Wang et al., 2016). Moreover, Ma et al. successfully synthesized spherical-like graphene oxide/$ZnFe_2O_4$/Ni nanohybrids through a simple hydrothermal approach. The most significant reflection loss (RL) occurred when the concentration of graphene oxide/$ZnFe_2O_4$/Ni nanohybrids was increased to 40%. At this concentration, the RL reached -22.57 dB at 4.21 GHz with a minimal layer thinness of 2.5 mm. Additionally, the absorption band-width (RL $\leq$ -10 dB) extended from 3.6 to 10.22 GHz, exhibited effective performance within a thickness between 1.5–4.0 mm. The researchers highlighted that these spherical graphene oxide/$ZnFe_2O_4$/Ni nanohybrids a novel candidate as an efficient microwave absorber in applications spanning communications, energy conversion, lithium-ion batteries, and defence constructions (Ma et al., 2019).

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CHAPTER 6

USE OF POLYMER MATRIX COMPOSITE MATERIALS IN AVIATION APPLICATIONS

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1. COMPOSITE MATERIALS

At the macro level, materials that are formed by the combination of two or more independent materials and have different properties than the materials that make them up are called composite materials. Composite materials are produced in a way that shows the best properties of the materials that make them up. Composite materials generally consist of two different structures: the reinforcement material and the matrix phase that holds this reinforcement material together. There is an intermediate phase between these two different structures. The reinforcement material is hard, discontinuous and higher strength, while the matrix phase is softer, lower strength and continuous. Composite materials can show different mechanical properties at the same time, thanks to this self-forming structure. While the reinforcement material provides strength and rigidity, the matrix material ensures that the reinforcement materials are bonded together, the load is distributed homogeneously and the reinforcement material is protected from chemical attacks. In addition, the matrix material prevents the progression of cracks that may occur in the transition to plastic deformation and delays the ruptures that may occur in the composite material (Ahir et al., 2008; Carlsson et al., 2013; Mazumbar, 2002; Parveez et al., 2022; Singh et al., 2019; Thor et al., 2020; Treviso et al., 2015).

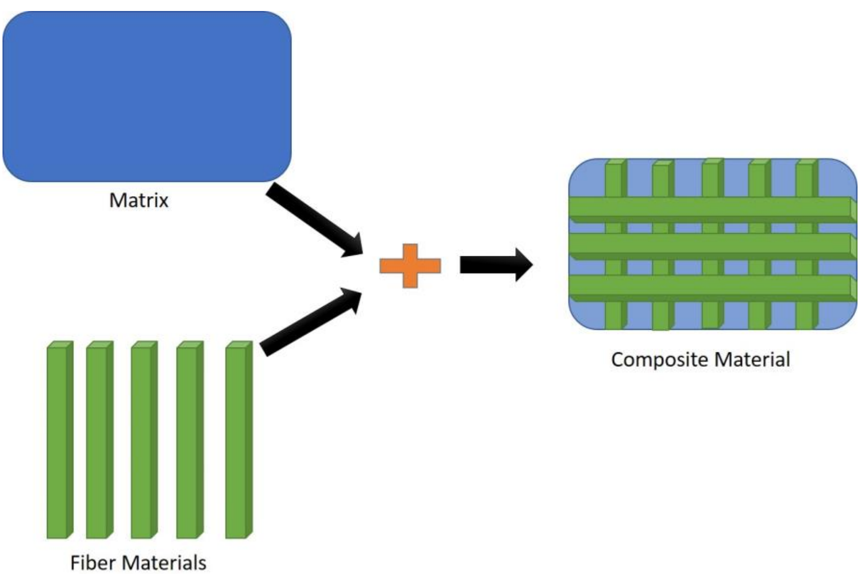

Figure 1. Fiber reinforced composite material structure

1.1. History of Composite Materials

Although composite materials do not have a very old history, they are actually one of the materials that have been studied for centuries. One of the oldest examples of this is composite materials produced by mixing clay and straw. The composite structure, made by combining clay and straw, was used in the walls of old buildings. These composite bricks increased the strength of buildings and enabled more solid structures to be obtained. Composite materials were produced by combining reed and mud in the construction of old boats, which ensured comfort and stability on the water. In addition, ancient civilizations used bamboo and wood composite materials in various construction and hand tools. In addition, it is known that combinations with various natural reinforcements are made to increase flexibility and strength in spring making. Approximately 200 years ago, the development of reinforced concrete, a composite structure, began by placing steel bars into the concrete matrix for the first time. Since the mid-1900s, various studies have been carried out on the production and development of glass, carbon and aramid fibers. These fibers have become one of the indispensable components of composite materials with high strength-to-weight ratio. Since the early 21st century, composite materials have become an important research topic for aviation and space applications. High strength and lightness, two indispensable parameters in the aviation industry, have become one of the most striking features of modern composite materials. Carbon fiber reinforced composites and aramid fiber reinforced polymer matrix structures are actively used in aviation applications today (Callister & Rethwisch, 2018; Godara et al., 2021; Hashin, 1983; Herakovich, 2012; Parveez et al., 2022; Vassilopoulos, 2020).

1.2. General Properties of Composite Materials

Composite materials can provide properties such as higher strength, easier shaping, better rigidity, lightness, vibration damping and corrosion resistance at a higher level than the structures that form them. In fact, under normal conditions, it is quite difficult to provide all these features at the same time. Due to their structure, composite materials provide the opportunity to increase the mechanical properties required depending on the place of use. Considering all these features of composite materials, some advantages and disadvantages emerge. These can be listed as follows;

Advantages of composite materials

- High specific stiffness and strength
- Easy to shape
- Electrical property
- Heat and fire resistance
- Vibration damping
- Resistance against corrosion
- Resistance to chemical effects
- Permanent coloring
- Aesthetic appearance
- More lightness
- Low radar visibility
- Design flexibility
- Dimensional Stability
- High impact resistance
- High thermal stability
- Creation of aerodynamic shapes not possible with wood or metal
- Composite materials have a long service life.

Disadvantages of composite materials

- Air particles in their structure negatively affect fatigue properties,
- They show different properties as a result of the load being applied in different directions,
- For the same composite material, operations such as tensile and compression cutting cause openings in the fibers, so precision manufacturing cannot be mentioned in such materials.
- Temperature limits
- Raw materials are expensive
- Difficulty manufacturing
- Damage detection is difficult
- Ingredients have limited shelf lives.
- There is no set standard for quality; instead, the material's quality is determined by the production procedures' quality (Carlsson et al., 2013;

Liu et al., 2015; Mazumbar, 2002; Sandhanshiv & Patel, 2020; Tanasa & Zanoaga, 2013; Zabihi et al., 2018).

Considering the change of composite materials from past to present, it is seen that people have done a lot of research to improve material properties and increase their use in various applications. More efficient solutions have been obtained in many different sectors, starting from the oldest composites to modern composites. Although studies continue today, composite materials have an important place in many areas, from the prosthetics (implant) industry, the maritime industry, the aviation and space industry, the automotive industry, sports equipment and the construction industry. Interest in composite materials is increasing day by day in the automotive industry and aviation, especially in order to save fuel by reducing weight. The use of composite materials in sports equipment is increasing day by day. Composite materials are extremely useful, especially for structures that require flexibility and durability. Tennis rackets, cycling sports, bows, golf clubs, boat paddles, snowboard boards and protective helmets are sports equipment where composite materials are frequently preferred. Some areas of use of composite materials today are;

- Home appliances
- Electrical and electronic industry
- Automotive industry
- Construction machinery
- Agriculture sector
- Construction industry
- Transportation sector
- Urban planning
- Furniture industry
- Space technology
- Maritime industry
- In the field of medicine (Manufacture of medical devices)
- Robotics
- Chemical industry
- Musical instruments industry

- Defence industry and aviation sector (Callister & Rethwisch, 2018; Egbo, 2021; Kumar Sharma et al., 2022; Mazumbar, 2002; Parveez et al., 2022).

2. TYPES OF COMPOSITE MATERIALS

Composite materials can be examined through three basic elements. These elements can be listed as matrix, reinforcement and additives. Matrix; It forms a continuous structure, either thermoplastic or thermoset. There is also the use of various types of resin. Reinforcement; glass fiber, carbon fiber, boron, alumina etc. These are the elements that provide strength to the matrix by using materials in different lengths and distributions. Contributions; These are materials added to the matrix material to give it different properties.

Composite materials according to their structural components (Kumar Sharma et al., 2022; Priyanka et al., 2017; Sandhanshiv & Patel, 2020; Singh et al., 2019);

- Fiber reinforced composites,
- Particle reinforced composites,
- Mixed composites,
- Layered composites.

Composite materials by matrix material;

- Polymer matrix,
- Ceramic matrix,
- Metal matrix (Callister & Rethwisch, 2018; Hasan et al., 2019).

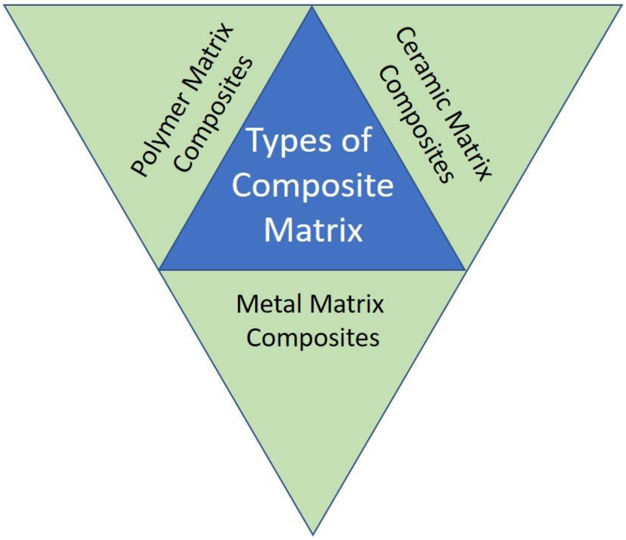

Figure 2. Composite materials by matrix material

2.1. Fiber Reinforced Composites

Thinned fibers are incorporated into the matrix to create this kind of composite. One important element that significantly influences the composite structure's endurance is the fiber dispersion throughout the matrix. Long fibers arranged parallel in the matrix have a high fiber direction strength, but a low perpendicular direction strength. Fiber reinforcements positioned in two dimensions can provide equal strength in both directions. An isotropic structure can be produced using a matrix structure with uniformly dispersed short fibers. One important component of the composite structure's overall endurance is the fiber's resilience. The amount of load on the fibers in the matrix grows with the ratio of the fibers' length to diameter. A crucial component of strength is also the perfect fiber structure. The structure of the bond between the fiber and matrix is a crucial component in the composite construction's durability. Gaps in the matrix structure suggest that there will be less contact with the fibers. Furthermore, the negative state of moisture absorption weakens the link between the fiber and the matrix.(Callister & Rethwisch, 2018; Sandhanshiv & Patel, 2020; Swolfs et al., 2019).

Fiber reinforcement types generally used are as follows;

- Glass fibers, (E-Glass, S-Glass)

- Carbon fibers, (Standard modulus, Intermediate modulus, High modulus, Ultra-high modulus)
- Aramid fibers, (Kevlar 29, Kevlar 49, Kevlar 149)
- Boron fibers,
- Silicon carbide fibers
- Alumina fibers
- Polyethylene fibers (Spectra 900 and Spectra 1000)
- Asbestos fibers

Fiber-reinforced composite materials, which have an important place especially in the aviation and space industry, are highly preferred in new generation aircraft thanks to the strength they provide to the structure. They also provide an advantage in terms of fuel economy thanks to their lightness. Thanks to their thermal stability, they have become a very attractive element for space vehicles (Egbo, 2021; Mazumbar, 2002; Shivi Kesarwani, 2017; Swolfs et al., 2019). Table 1 shows the reinforcement materials used in aviation applications.

Table 1. Comparisons between reinforcement materials used in the aerospace industry (Das et al., 2020; Mazumbar, 2002; Tanasa & Zanoaga, 2013).

<table>
<tr><th colspan="2">Fibers</th><th>Strength (Gpa)</th><th>Density (g/cm^3)</th><th>Modulus (Gpa)</th><th>Application of aerospace</th></tr>
<tr><td rowspan="2">Glass</td><td>S-glass</td><td>4.4-4.8</td><td>2.47</td><td>85-95</td><td>Highly loaded parts</td></tr>
<tr><td>E-glass</td><td>2.2-2.6</td><td>2.55</td><td>65-75</td><td>Small passenger aircraft parts, radomes, rocket motor casings</td></tr>
<tr><td>Boron</td><td>3-; 4-; 5.6-mil Boron</td><td>3.6-4.0</td><td>2.38-2.54</td><td>380-400</td><td>Structural reinforcement; thermal and radiative deflectors</td></tr>
<tr><td rowspan="2">Carbon (modulus)</td><td>Ultra-high</td><td>7.0-7.5</td><td>1.80-1.82</td><td>290-310</td><td>Primary structural parts in high performance fighters, spacecrafts</td></tr>
<tr><td>High</td><td>2.8-3.0
4.0-4.5</td><td>1.77-1.80</td><td>390-450</td><td>Space structures, control surfaces</td></tr>
</table>

	Intermediate	5.4-5.7	1.77-1.81	270-300	Primary structural parts in high performance fighters
	Standard	3.0-3.5	1.77-1.80	220-240	Widely used for almost all types of parts, satellites, antenna dishes, missiles, etc.
Aramid (modulus)	**High**	2.3-2.4	1.48	160-170	Highly loaded parts
	Intermediate	2.7-2.8	1.44	120-128	Radomes, some structural parts; rocket motor casings
	Low	2.7-2.8	1.44	80-85	Fairings; unloaded bearing parts
Alumina	-	3.4	2.58	76	It is used in parts that require insulation.

2.2. Particle Reinforced Composites

It is formed by the presence of different types of material in the form of particles within the matrix structure. Such materials have an isotropic structure, that is, their properties are the same in all directions. Their strength depends on the hardness of the particles they contain. Metal particles, often contained within a polymer matrix, are a common example of this type of material. The presence of these metal particles enables the material to gain thermal and electrical conductivity properties. On the other hand, structures containing ceramic particles in the metal matrix have high hardness and high temperature resistance. Such composite materials are especially preferred in the production of aircraft engine parts (Callister & Rethwisch, 2018; Egbo, 2021; Shivi Kesarwani, 2017).

2.3. Mixed Composites

It is possible to contain more than one type of fiber in the same composite structure, and such composites are called hybrid composites. Hybrid composites offer a fertile field for the development of new types of materials. For example, Kevlar is an economical and durable fiber type, but its compressive strength is slightly low. On the other hand, graphite has low toughness, it is also expensive but has strong compressive strength. In the hybrid composite structure where these two different fibers come together, the toughness is higher and the cost is lower than that of graphite alone. At the same time, its compressive strength is higher than kevlar fiber composite (Callister & Rethwisch, 2018; Egbo, 2021; Shivi Kesarwani, 2017).

2.4. Layered Composites

Layered composite structures are one of the oldest and most widely used types of composites. The combination of layers with different orientations allows for the attainment of very high strength values. These structures are resistant to factors such as heat and moisture. Their lightweight nature and, simultaneously, high strength make them preferable over metals. Continuous fiber reinforced layered composites, in particular, find extensive use in aircraft structures, serving as surface coating material for wings and tail sections. Additionally, sandwich structures, widely employed in aircraft construction, are also examples of layered composite materials (Callister & Rethwisch, 2018; Egbo, 2021; Mazumbar, 2002).

The matrix structure in composite materials are important parts that hold the fibers together, distribute the load homogeneously among the fibers, and provide damping against future impacts (Hasan et al., 2019; May et al., 2020; Shivi Kesarwani, 2017).

Composite materials according to matrix type;

2.5. Polymer Matrix Composites

Polymer matrix composites (PMK) are one of the most frequently used engineering materials today. This achievement has been made possible by advances in high-performance fibers (e.g. carbon, polyethylene, aramid) as well as advances in polymers used as matrix materials. However, the mechanical properties of polymers remain low compared to other building materials. For this reason, polymer matrix composite materials need to be constantly developed. PMK materials are frequently used as building materials in engineering applications today, thanks to their easy production methods and improved structures. High temperature and pressure are not required for the production of PMK materials, which facilitates the production of complex shaped parts. Low temperature enables production without degradation of reinforcement elements. The equipment required for the production of PMK materials is simple and easy to use (Callister & Rethwisch, 2018; Egbo, 2021; Kumar Sharma et al., 2022; Sandhanshiv & Patel, 2020; Shivi Kesarwani, 2017; Singh et al., 2019).

2.6. Ceramic Matrix Composites

The structure formed by different reinforcements within a ceramic matrix phase is called ceramic matrix composite materials. SMK materials reinforced with different fibers or particles are a frequently preferred material group for engineering applications. They are used in military applications, aviation and space studies. SMK materials are used as the construction material of furnaces used in the construction of aircraft materials, and in gas turbines and heat engines of aircraft (Callister & Rethwisch, 2018; Egbo, 2021; Hasan et al., 2019; May et al., 2020; Sandhanshiv & Patel, 2020).

2.7. Metal Matrix Composites

Metal matrix composites are structures formed by combining the metallic phase with reinforcement materials using various techniques. Melting, hot pressing, vacuum impregnation, etc. of metal matrix composite materials. It is possible to obtain these methods. Since the matrix phase consists of a metallic material, MMC materials offer the opportunity to work at high temperatures. MMC materials, which are known by different names depending on the shape of the reinforcement material they contain, are frequently preferred in aviation and space materials. It is used in the reflector parts of space telescopes, aircraft bodywork and engine parts, platform carrier equipment and space communication devices (Callister & Rethwisch, 2018; Egbo, 2021; Hasan et al., 2019; Lakshmikanthan et al., 2022; May et al., 2020; Sandhanshiv & Patel, 2020).

3. USE OF POLYMER MATRIX COMPOSITE MATERIALS IN THE AVIATION INDUSTRY

The biggest factors in the use of composite materials in the aviation and space industry are their lightness and strength properties. These advantages play an important role in reducing fuel consumption, increasing durability and reaching high speeds easily. In addition to these properties of composite materials, they have vibration damping, high fatigue and heat resistance, easy shaping, low radar visibility, etc. It appears to have different important advantages. (Blanco et al., 2021; Callister & Rethwisch, 2018; Das et al., 2020; Hasan et al., 2019; Kumar Sharma et al., 2022; Mazumbar, 2002; Parveez et al., 2022; Shivi Kesarwani, 2017). In spacecraft, polymer matrix composite materials are used in tails, body coating materials, and solar panels, and development studies are continuing. The body part of some satellites is made entirely of PMC material. The wave guide, feed hom antenna, shear panels, and carbon fiber tubing of the satellites are made of PMC materials. The nose parts of helicopters, the majority of the outer body, tail parts, propellers, doors and many other parts are made of PMC materials. PMC materials are used in large quantities in the fuselage parts of passenger and cargo aircraft used today. PMC composite materials are frequently used in the vertical tail boxes, wing parts, nose parts, air intakes, some parts of the engine section, exhaust flaps, fuel pumps, inlet slots and external fairings of the turbines of the same aircraft. In warplanes; Important parts such as nose parts, tail parts and speed brakes are produced from PMC materials (Abbas et al., 2018; Blanco et al., 2021; Das et al., 2020; Kumar Sharma et al., 2022; May et al., 2020; Sharma & Srinivas, 2020; Singh et al., 2019). With the developments in polymer matrix composite materials, it is thought that these materials will have much more usage areas in the aviation and space industry.

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CHAPTER 7

INFLUENCE OF TOOL ADVANCING SPEED ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF FRICTION STIR LAP WELDED 7075-T651 AL ALLOY SHEETS

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1. INTRODUCTION

7075 aluminum (Al) alloy, a precipitation-hardened wrought alloy, is one of the strongest aluminum alloys and has a great strength-to-weight ratio and natural aging properties. Therefore, many aircraft structural parts are produced from this alloy (Feng et al., 2010; Fuller et al. 2010). Nonetheless, joining 7075 Al alloy with traditional fusion welding processes is quite challenging because it has copper that is highly likely to cause weak weld formation by causing the formation of cracks in the weld and the heat-effected zone (Fu et al., 2011; Rajakumar et al., 2011). Furthermore, in the fusion welding of 7075 Al alloy, porosity and lack-of-fusion issues are also seen (Gupta et al., 2006). As a result, conventional fusion joining methods remain incapable of joining 7075 Al alloys (Mao et al., 2014). On the other hand, friction stir welding (FSW) which is a solid-state welding technique, is efficient in terms of energy, adaptable, and environmentally friendly in comparison to the fusion welding methods (Thomas et al., 1991). By the FSW technique, materials are joined without being melted (Su et al., 2003). Therefore, this welding method has the advantage of joining even 7XXX series aluminum alloys that cannot be welded with fusion welding processes. In addition, the FSW considerably eliminates the formation of cracks and porosity and thus significantly enhances joint strength (Jata et al., 2000; Nandan et al., 2008; Rhodes et al., 1997). Despite the fact that the FSW technique was primarily created for joining Al alloys (Rajakumar et al., 2011; Rafi et al., 2010; Balasubramanian, 2008; Giorgi et al., 2009). It also has a lot of potential for joining other materials such as steels, titanium alloys, magnesium alloys, metal matrix composites, and dissimilar materials (Rose et al., 2011; Ramirez and Juhas, 2003; Fujii et al., 2006; Amirizad et al., 2006; Abdollah-Zadeh et. al, 2008; Chen et al., 2008). Many lap joints in manufacturing sheet metal structural bodies in the aerospace industry are used. For instance, stringers are joined to the skin by lap joints in aircraft fuselages (Salari et al., 2014; Galvão et al., 2013). The FSW method has mostly been utilized to join Al alloys in butt joint configuration. FSW has recently been applied in the fabrication of lap joints, broadening the range of uses that could profit from it (Lee et al., 2008). Applying the FSW rather than riveting for joining Al alloys in lap joint configuration can considerably save weight and cost with higher joint strength and less manufacturing complication (Babu et al., 2012). The FSW variables influencing material flow, heat input, and joint quality are the tool welding rate, rotational rate, tilt angle, axial force, and shape (Cam, 2011; Leal et al., 2008; Kumar and Kailas 2008). These process variables need to be carefully selected to achieve maximum weld strength (Ahmadi et al., 2014). Song et al. (2014) investigated friction stir lap welding (FSLW) of dissimilar AA2024 and AA7075 Al alloy sheets at tool travel speeds of 50, 150, 225 and 300 mm/min using a fixed tool rotation speed of 1500 rpm (revolutions per minute). In general, it has been found that a higher-strength weld is produced with a higher tool travel speed. Lee et al. [2008] studied FSLW of different Al alloys of 5052 and 6061 using tool rotational rates ranging from 1250 to 3600 rpm for a constant tool travel speed of 267 and also using tool travel speeds ranging from 127 to 507 mm/min for a constant tool rotation speed of 1600 rpm. According to the achieved results, a stronger weld was produced at a higher tool travel speed (Lee et al., 2008).

The FSW has been generally applied for joining metal sheets butt configuration. Using the FSW for lap joining sheet metal is not much and there is no study found in the literature about FSLW of 7075 aluminum alloy sheets. Therefore, the FSLW of 7075 aluminum alloy sheets was studied in this investigation by studying one of the most important parameters of tool feed rate.

2. MATERIALS AND METHODS

7075-T651 aluminum (Al) alloy sheets with 2 mm thickness were combined by friction stir lap welding (FSLW). The chemical and mechanical aspects of the alloy are given in Tables 1 and 2. Sheets were joined for 3 different tool welding speeds (21, 36 and 52 mm/min) while keeping the tool at a tilt angle of 2 degrees clockwise, 3.8 mm penetrating depth and 1000 rpm rotation speed constant as shown in Figure 1. The tool utilized in welding processes was fabricated from H13 tool steel and it has a 16 mm flat shoulder and a 3.5 mm long cylindrical screw pin with a right screw M5x0.8 mm. FSLW welds produced are presented in Figure2. The welds were cut to acquire the samples for tensile shear test, microstructure inspection and hardness measurement. The samples for the tensile shear is shown in Figure 3. The tensile shear test was carried out using SHIMADZU machine using 2 mm/min tensile speed as demonstrated in Figure 4. AOB inverse metal optical microscope for microstructure examination, THV-1D Vickers hardness machine for hardness measurement and Scanning Electron Microscope (SEM) for fracture surface examination are used. No imperfections, for example, cracks, voids, etc. were detected on the weld bead from the photograph of the welds made in Figure 2.

Table 1. 7075-T651 Chemical composition

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Weight (%)	0.4	0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	5.1-6.1	0.2	Rest

Table 2. 7075-T651 Mechanical features

Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
555	465	10

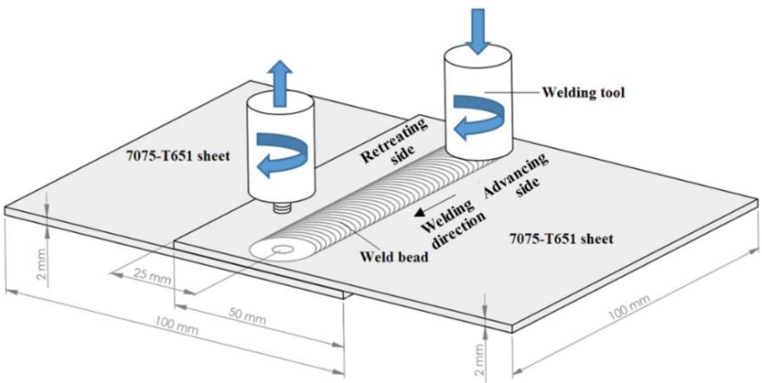

Figure 1. Showing FSLW operation by schematic

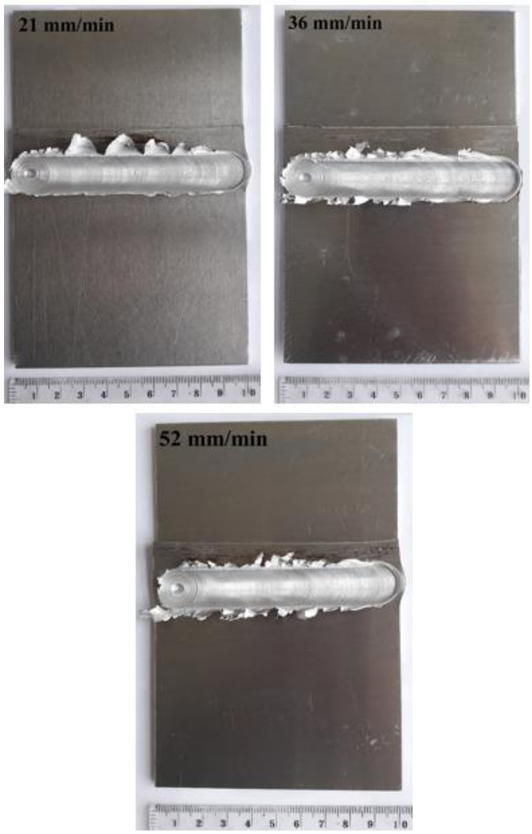

Figure 2. The photos of the welds manufactured at various tool advancing speeds

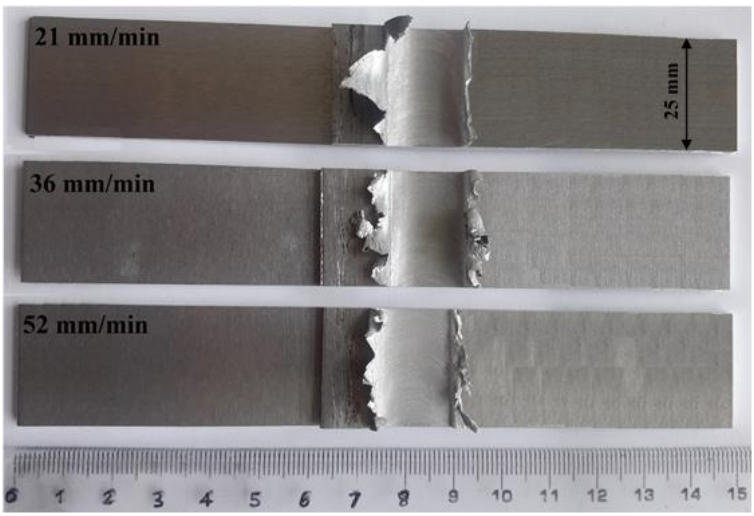

Figure 3. Weld samples for tensile shear test

Figure 4. Tensile testing the welded specimens

3. RESULTS AND DISCUSSION

Macro cross-sections of the produced welds are given in Figure 5. No visible defects like cavities or voids, and cracks were detected on the sections. For each weld, the joint width at the interface of the sheets was measured on the optical microscope and the largest weld width was found for the weld formed at 21 mm/min. Moreover, it was seen that joint width reduced slightly when the feed rate was improved from 21 to 52 mm/min.

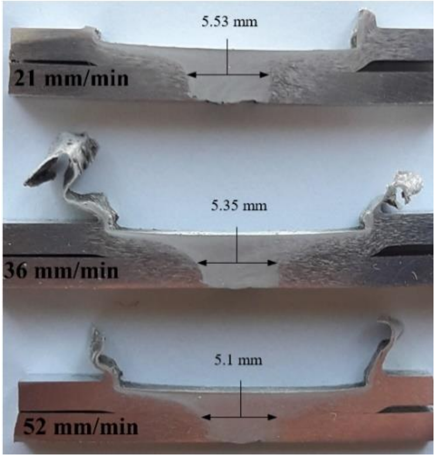

Figure 5. Macro cross-sections of the manufactured welds

Figure 6 shows the microstructures taken from the center of the welds made at various tool feed rates. It can be seen that the weld created at 21 mm/min has a microstructure with the smallest grains, while the microstructure of the weld generated at 52 mm/min contains the largest grains. The weld of 21 mm/min has a microstructures containing smaller because of the materials being exposed to more heat, plastic deformation, and recrystallization.

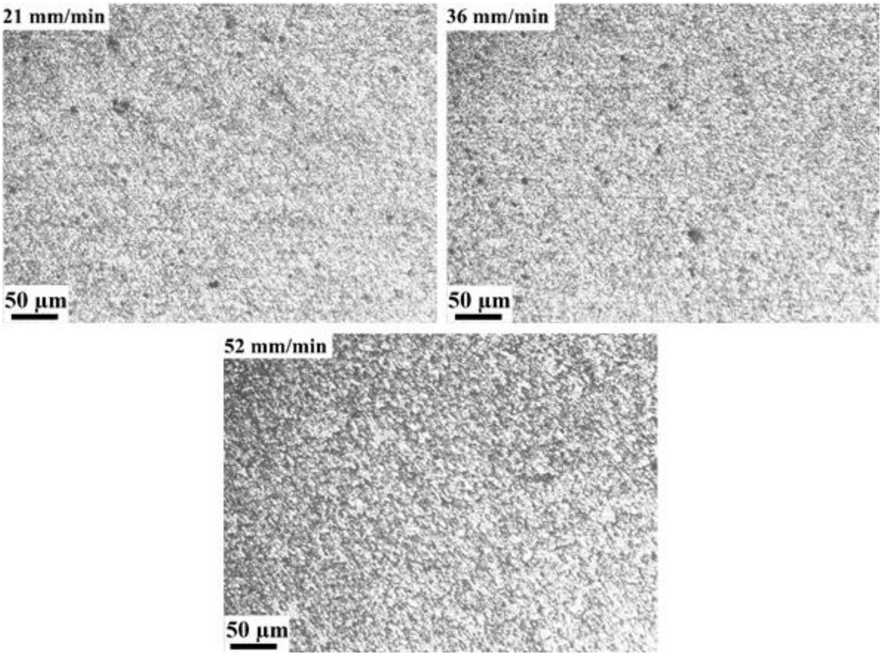

Figure 6. Microstructures at centers of the welds

Figure 7 indicates the microstructures obtained from different regions on the cross-section of the weld made at 51 mm/min. BM, WR, TMAZ and HAZ represent base metal, weld region, thermos-mechanically affected zone and heat-affected zone, respectively. It is clear that all these regions have different microstructures. BM has elongated grains because of the applied rolling operation. It can be seen that WR consists of finer grains in comparison of the TMAZ and HAZ. TMAZ has elongated and curved grains due to the deformation of the tool rotation action, while HAZ possesses round and elongated grains slightly similar to that of the BM. Such microstructures were also encountered in other studies (Kumar et al., 2023).

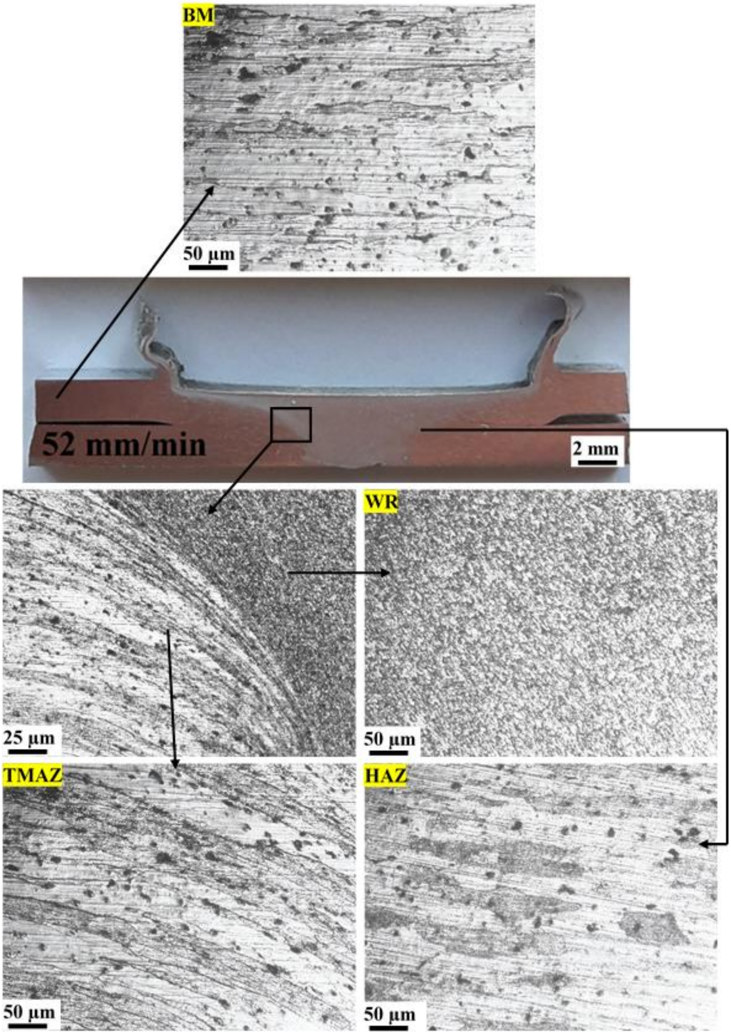

Figure 7. Microstructures of different regions on the weld of 52 mm/min

Avarage Vickers microhardness values of the regions on the cross-section of the weld made at 21 mm/min is provided in Figure 8. The hardness of the BM region was found to be 171 HV, while the hardness in the regions of the HAZ, TMAZ and WR was determined to be 152, 155, and 164 HV, respectively. In general, the hardess of the WR was higher than that of the HAZ, TMAZ for all the welds. Moreover, the hardness in the WR for 21 mm/min was higher compared to other welds. This is likely because the weld made at 21 mm/min had finer grain in its WR. In other investigations the highest hardness values were also found in WR (Yazdanian et al., 2012; Babu et. al., 2012).

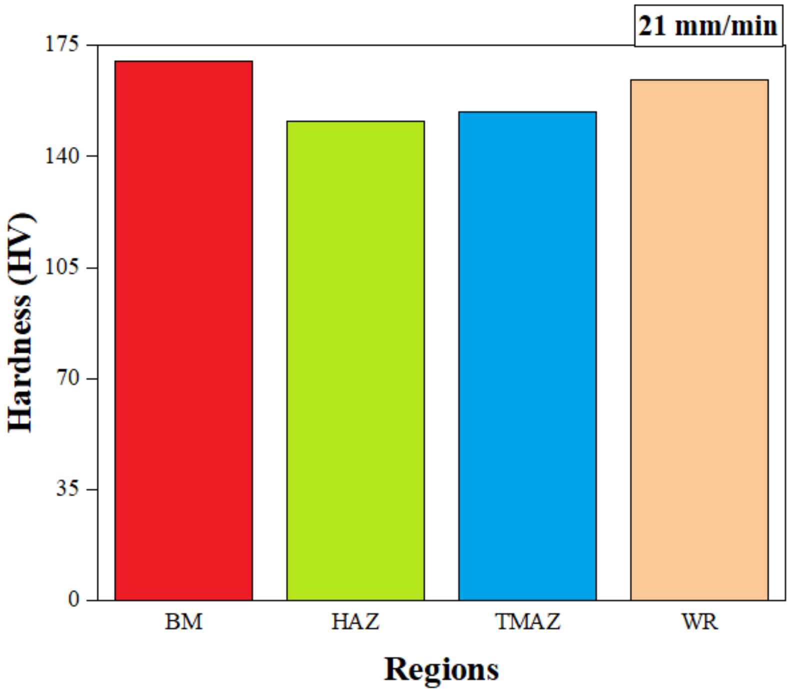

Figure 8. Hardness of the different areas

The obtained tensile shear loads of the welds are presented in Figure 9. As seen the weld created at 21 mm/min performed the highest strength, while the one made at 52 mm/min had the lowest strength. In addition, it is evident that the weld strength gradually decreased when the tool travel speed was increased from 21 to 51 mm/min. The weld of 21 mm/min is the strongest because this welding speed supplied a more appropriate heat input for mixing the sheets' materials being welded and thus this weld a has bigger bonding area as shown in Figure 5, and smaller grains in its microstructure as indicated in Figure 7. According to Tucci et al. (2021), tool feed rate (welding speed) has a dominant role on mechanical properties of joint in the FSLW of 2198 and 6082 Al alloys. In addition, it was found that improving tool feed rate from 60 to 120 mm/min led to a reduction in the strength of the produced weld.

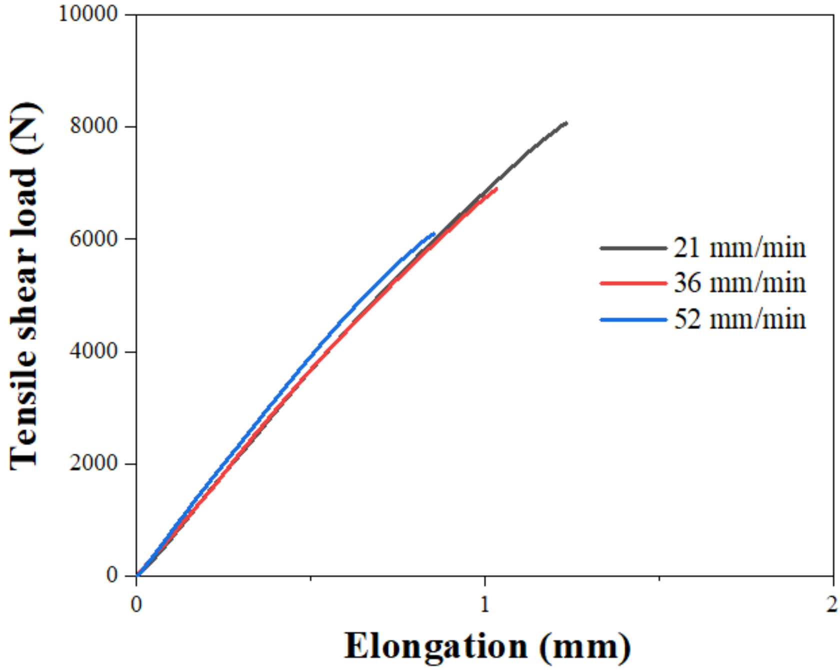

Figure 9. Tensile shear load results for the welds

Figure 10 shows front and rear view photographs of the broken samples after tensile testing. It can be seen that all the specimens failed from the lower sheet and on the RS as exhibiting tensile-type fracture. Furthermore, Moreover, it is clear that the fracture first begins from the interface of the sheets at the RS and then proceeds downwards towards the weld region and fractures from the weld region for all the joints. Since joint area size and quality are higher for the weld of 21 mm/min, the weld fracture area exposed to tensile load is the highest. On the other hand, since the joining area and quality for the weld of 52 mm/min are lower than others, it broke straight from the weld region.

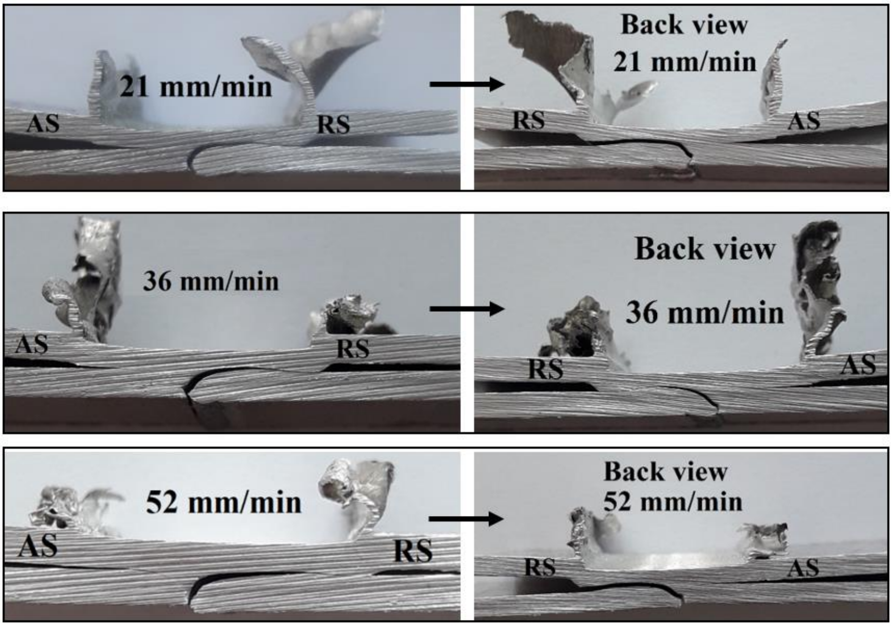

Figure 10. Macro fractured views of weld tensile samples after tensile test

The SEM image of the weld fracture area surface for the weld made at 21 mm/min feed rate is shown in Figure 11. It can be seen that it contains many small dimples. Therefore, it can be said that it is a ductile fracture.

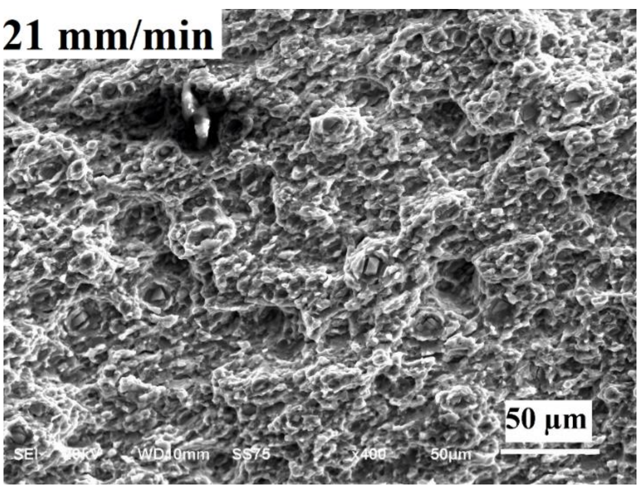

Figure 11. Fracture surface image of the weld of 52 mm/min

4. CONCLUSIONS

7075-T651 Al alloy sheets were successfully welded by the FSLW method for various tool advancing speeds. It has been observed that tool feed has a very important effect on weld microstructure quality and therefore mechanical properties. By increasing the tool advancing speed, a weld with better strength formed, and the strongest weld having a tensile shear load of 8077 N was achieved at the maximum feed rate of 52 mm/min used. The weld of 52 mm/min performed higher strength compared with other welds because it had a higher quality microstructure, a bigger bonding area, and more hardness at the joining interface.

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CHAPTER 8

THE IMPORTANCE OF AGRICULTURAL AVIATION IN PLANT PROTECTION

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1. INTRODUCTION

Meeting people's food demands has become one of the most critical concerns that nations are focusing on these days. The world's population is expanding quickly but its geographical area stays the same, despite best efforts. Furthermore, roads, industrial facilities, new settlements, and erosion are all contributing to the progressive loss of agricultural land (Friha et al., 2021; Inoue, 2020). Since more land cannot be added, current methods and inputs can be used to enhance the amount of product produced per unit area. Among the techniques to boost the output are irrigation, appropriate tillage, fertilization, breeding, correct harvesting, establishment of producer associations, mechanization, and use of contemporary plant protection techniques. "Plant protection" refers to any activity done to financially shield plants from the harm caused by pests, diseases, and weeds that reduce crop yield, hence increasing agricultural output and enhancing its quality (Kadıoglu, 2012).

Plant protection has a long history worldwide. Sulfur is known to have been utilized in ancient cultures to treat certain plant illnesses, but genuine research on plant protection began in the 19th century when Pasteru discovered bacteria associated with a number of plant and animal ailments (Anonymous, 2023a).

In order to meet their food demands, countries are forced to purchase agricultural products. Plants and herbal goods swiftly cross-national borders and spread throughout the world, as do numerous compounds derived from plants and used in herbal products. In the modern world, plants are exchanging rapidly and widely. (Özgüven and Közkurt, 2021). Plant and crop pieces are thereby quickly and widely distributed. They spread extremely deadly diseases, bugs, and weeds with them. Clean spaces quickly get contaminated with dangerous chemicals if preventative measures are not followed. These agents spread quickly now, but in the past, they took a long time to propagate.

The goal of agricultural control nowadays is to raise production and quality while staying within financial bounds, as there is no space for unprofitable methods in contemporary plant protection. One of the most important principles of our day is affordability, as is well acknowledged. The economy of modern plant protection encompasses not only the prevention of new issues, like new pest, disease, or weed species becoming prevalent, through educated and controlled procedures, but also the preservation of the environment and human health. It also entails preventing residual issues in agricultural exports as well as the establishment of pesticide-resistant individuals.

Agricultural control aims to recover as much of the product losses as possible by efficiently combating plant diseases, pests, and weeds, which generate considerable product losses of 20–40% by destroying our plant goods. "People harvest not what they sow, but what is left over from diseases and pests, and lose some during harvesting, transportation, and storage," is a proverb that everyone in this field is familiar with. This proverb serves as the foundation for this control.

Diseases, pests, and weeds will undoubtedly harm these plants and result in large crop losses, regardless of how carefully the soil is cultivated, how high-quality seeds are used, how many certified seedlings and saplings are planted, or how well the plant is nourished. Crop losses can amount to as much as 65% or even 75–80% in certain cases if disease, insect, and weed control measures are not taken.

It is not reasonable to ignore these 65% agricultural losses when millions of people throughout the world struggle to make ends meet (Anonymous, 2023b). As a result, fighting off weeds, pests, and plant diseases is unavoidable. In the sphere of agricultural control, contemporary techniques have recently been applied. Among these, aerial spraying techniques are the most significant. The most popular technique in this field for agricultural control is the deployment of drones, or unmanned aerial vehicles.

2. HISTORY DRONES

The term drone has been used from the early days of aviation, being applied to remotely flown target aircraft used for practice firing of a battleship's guns, such as the 1920s Fairey Queen and 1930s de Havilland Queen Bee. Later examples included the Airspeed Queen Wasp and Miles Queen Martinet, before ultimate replacement by the GAF Jindivik (Anonymous, 2023c)

The term remains in common use. In addition to the software, autonomous drones also employ a host of advanced technologies that allow them to carry out their missions without human intervention, such as cloud computing, computer vision, artificial intelligence, machine learning, deep learning, and thermal sensors. For recreational uses, an aerial photography drone is an aircraft that has first-person video, autonomous capabilities, or both. Since the late 1990s, unmanned aerial vehicles have also been used for agricultural spraying. This phenomenon started in Japan and South Korea, where mountainous terrain and relatively small family-owned farms required lower-cost and higher-precision spraying. As of 2014, the use of UAV crop dusters, such as the Yamaha R-MAX, is being expanded to the United States for use in spraying at vineyards (Anonymous, 2023d).

In Türkiye, the first drug control against Sunn pest was started in 1955, using pesticides using ground equipment and aircraft. In 1979, ULV applications started with aircraft (Gökdoğan, 2015).

3. DRONE TECHNOLOGY IN AGRICULTURE

Given their ability to save money and time, drones, whose usage in agriculture has grown recently, will become increasingly more common in the years to come. Drones are more than just software. It is an effective technique that came about as a result of two-way communication with farmers and others who knew enough about agriculture. With the help of agricultural engineers, farmers can utilize this technology with ease and maximize its benefits. Agriculture will inevitably become more mechanized in the world due to rising labor costs and farmers moving to non-agricultural industries. While other technologies have great promise, the world is now progressing mechanization mostly through the employment of machinery and equipment for planting and harvesting. One is the use of Unmanned Aerial Vehicles (UAV), which in economies with more sophisticated agricultural systems is still relatively new. The technique is expected to decrease the requirement for labor, improve pesticide targeting, and decrease usage (Wachenheim et al., 2021). Agriculture is an important industry for the sustainability of life, in addition to being a substantial field of effort that increases employment and national income, gives raw materials to non-agricultural sectors, and both. Technology is advancing quickly, which has resulted in the development of new agricultural instruments and techniques that have streamlined and increased the effectiveness of agricultural applications. Drone use in agriculture has become a popular technological innovation in recent years and is expected to continue rising as more application areas are added. Because of their ubiquity, scholars from subjects other than agriculture are interested in studying the widespread use of drones in agriculture. Because people in many fields related to agriculture lack technical knowledge, there may be false information or inefficient usage of drones in agriculture (Özgüven et al., 2022). In Southeast Asia, the use of drones for spray treatments is growing; in South Korea, they handle more than 30% of all agricultural spraying. Drone sprayers can reach areas that are very difficult to access, including steep tea fields at high altitudes. Workers no longer have to risk their health while traversing fields with backpack sprayers thanks to drone technology. Drone sprayers increase production and save chemical expenses by providing exceedingly thin spray treatments that may be targeted to precise places. The national laws governing drone spraying today differ greatly from one another. While they can also be used for military, photographic, and agricultural purposes, drones are mostly used for flight and navigation.

Deep learning, planting and seeding, spray application, security, drone irrigation, drone pollination, and scouting/monitoring plant health are just a few of the agricultural applications for drones. (Debangshi, 2021).

3.1.Spray Application

A prior study focused on the development of agricultural spray systems for tiny unmanned aerial vehicles (UAVs), which included the use of specialized electrostatic rotary atomizers (Ru et al., 2011). It has been emphasized that payload capacity constraints necessitate limited volume applications. Additional research has concentrated on the development of on-board monitoring systems to facilitate the ground-based operator's situational awareness of the UAV's status and the application of numerous UAVs working in coordinated fleets for spray application (Sugiura et al.; 2005; Wang et al., 2013).

Unmanned aerial vehicles (UAVs) possess significant potential for aerial spraying in many Asian regions, such as Korea and Japan, where the majority of fields are fragmented or small-scale. The Japanese company Yamaha Corporation invented the idea of unmanned aerial vehicles for farming purposes. Worldwide, numerous nations have used Yamaha helicopters as research platforms. But the export of helicopters made by Yamaha was outlawed in 2007 to prevent others from using their technology (Xue et al., 2016).

One of the trickiest aspects of farming is agricultural spraying, which is crucial in the battle against pests and illnesses. But if not done properly, this activity, which has advantages and disadvantages, might jeopardize the health of individuals as well as the integrity of the natural world. The health of the applicator, who is continuously exposed to agricultural pesticides, is concerned about the success of agricultural pesticide application, which depends on numerous aspects such dosage, application method and time, use of protective work equipment, season, and weather conditions. Drone models provide quick, useful, and affordable agricultural pesticide solutions in the field of agricultural production, as they do in many other spheres of life, protecting the environment and public health (Wang et al., 2020).

Figure 1. Spraying drones (www.drone.net.tr)

3.1.1 Benefits of Spraying with Drone

There are numerous benefits to using pesticide drones, both environmentally and economically, and their use is growing daily. Farmers, local government officials, agricultural engineers, technical staff, and producers of agricultural inputs have achieved successful outcomes in drone spraying applications, which has sped up the adoption of this technology by new users. Drone varieties (Figure 1) that are manufactured with varying technical features for varying goals and objectives successfully carry out their tasks in every crop type and location across the nation. Using drones for spraying has the following primary advantages:

- Provides increased productivity: Thanks to the use of agricultural pesticide drones, agricultural pesticide products applied evenly and balanced show maximum effect in combating the target disease or pest. The product, which reaches the entire field or garden, the crop, and all vegetative organs such as branches, leaves, stems and buds in equal and balanced amounts, helps to minimize yield losses by showing more effective success in agricultural control.
- Reduces environmental pollution: Issues like improper dosing and uneven field distribution, which are common, particularly when applying pesticides and herbicides by hand, put the environment and public health at serious danger. However, far less pesticide may be sprayed consistently and uniformly over a greater area when using professional drones to apply pesticides. Unmanned aerial vehicle technology is a particularly useful tool for farmers since it minimizes the usage of agricultural chemicals, shields applicators from pesticide exposure all the time, and helps them avoid financial losses.
- Reduces agricultural input costs: The agricultural machinery and equipment park that each farmer must own individually can cause quite high costs. Many equipment such as pulverization equipment, high pressure pumps, liquid mixture tanks, hoses and reels, which must be owned according to the crop grown and the geographical conditions of the agricultural land cultivated, result in initial investment and subsequent maintenance/repair costs. However, thanks to agricultural drone technologies, more effective pesticide applications can be made at much more affordable costs by using an application-based service procurement system according to the size of the agricultural land. While many input items such as labor, inventory depreciation and operating expenses decreased; Obligations such as maintenance and repair and spare parts availability are also eliminated (Manfreda et al., 2018; Tsouros et al., 2019; Radoglou-Grammatikis et al., 2020).

Although drone spraying in agriculture has many benefits, it also has some disadvantages.

•Agricultural Drone Spare Parts Problem; as with all drone models of agricultural drone manufacturers around the world, there is a battery problem. Additionally, the high dollar exchange rate increases drone prices significantly.

• GPS Connection problem; often, online coverage is not available in rural areas. Under these conditions for agricultural drones operating completely autonomously when spraying, a farmer must invest in internet connectivity, which can become a recurring expense.

• Only operate in suitable weather conditions; drones fly largely depending on good weather conditions and spraying can be done. Flying a drone in rainy or windy weather conditions is dangerous. It limits the duration of drone use in agriculture.

• Information and skill; using new technology may sound nice, but using it on a daily basis requires the right skills and sufficient knowledge. A farmer who does not know how to use a drone must either acquire the knowledge or stick with an experienced drone pilot (Anonymous, 2023e).

3.2. Monitoring Field Conditions

The state of the field and the condition of the soil are also being monitored using drone field monitoring. Growers can identify any anomalies in the field by using the precise field mapping that drones can give, which includes elevation data. Knowing the elevation of the field helps determine drainage patterns and wet/dry zones, which makes it possible to apply irrigation tactics that are more effective. A small number of agricultural drone vendors and service providers furthermore offer soil nitrogen level monitoring through the use of upgraded sensors. This enables accurate fertilizer application, eliminating problematic growth regions and improving soil health for many years to come (Ahirwar et al., 2019).

3.3. Planting and Seeding

One of the more modern and uncommon use of drones in agriculture is seed planting. Although their current application is mostly in the forestry sector, automated drone seeders may soon find wider application. Replanting in exceedingly difficult-to-reach areas is achievable without endangering humans thanks to drone planting. They are also able to plant significantly more efficiently, with a team of two operators and ten drones capable of planting 400,000 trees every day (Fortes, 2017; Debangshi, 2021).

3.4. Scouting/Monitoring Plant Health

One use of drone imagery that has already been applied quite well is plant health monitoring. The Normalized Difference Vegetation Index (NDVI), a specialized imaging tool used by drones, uses precise color data to represent the health of plants. This enables farmers to keep an eye on their crops as they develop, allowing them to address any issues quickly enough to save the plants. This image illustrates how the NDVI works in its most basic form. Drones with "regular" cameras are another tool used to check the health of crops. Many farmers currently use satellite photos to monitor crop growth, density, and coloration. But employing closer drone imagery is often more efficient than getting satellite data, which is also costlier. Drones fly close to fields; therefore, cloud cover and low light levels are less significant than when using satellite imagery. While drone imaging can produce exact image location to the millimeter, satellite imaging may only provide precision to the meter. This makes it possible to identify stand gaps in newly planted areas and replant them as necessary. It also makes it possible to quickly identify and address any disease or insect issues (Yue et al., 2012; Debangshi, 2021; Chakraborty, 2023).

3.5. Security

Drone security is a fast-growing industry outside of agriculture that is also very beneficial to farm management. Without requiring human assistance, drones can monitor far-flung regions of a farm, saving time and allowing for more frequent examination of hard-to-reach places. Drone cameras are useful for finding used equipment and providing a daily summary of farm operations to ensure that everything is proceeding as planned. Security drones can be deployed to keep an eye on the gates and perimeters of more costly crops, like cannabis, rather than recruiting more guards. Drone cameras are also being creatively used to protect farm animals by locating missing or injured herd animals in isolated grazing areas. Monitoring from a remote location was once necessary (Anonymous, 2023f).

3.6. Drone Irrigation

There is also interesting new potential for drone use in agriculture thanks to Australian research. Developing more effective irrigation techniques is essential as drought conditions are impacted by climate change more and more. Drones are able to obtain very precise data on soil health, including moisture levels, without interference from plants by using microwave sensors. This implies that, in an attempt to conserve resources, water can be applied on a field (Figure 2) (Akkuş and Çalışkan, 2020; Agüera et al., 2011).

Figure 2. Irrigation with drone
(https://www.croptracker.com/blog/drone-technology-in-agriculture)

3.7. Drone Pollination

Drones are still being developed and evaluated for use in some of the more modern agricultural applications. One of the most well-known (and often made-up) uses of drone technology is drone pollination. Researchers in the Netherlands and Japan are developing small drones that are safe to use for pollinating plants. The next step is to construct autonomous pollination drones that can keep track on crop health even in the absence of constant operator supervision. (Anonymous, 2023f; Chakraborty, 2023).

4. CONCLUSION

The agriculture sector has already seen a significant change from drones, and this trend will only intensify in the years to come. Drones are becoming more and more useful for small farms, particularly in developing nations, but they won't become a standard piece of equipment for any farmer just yet. Drone usage laws need to be created or amended in many countries, and more research is required to find out how successfully these devices do specific tasks like spraying and administering insecticides. Farmers can benefit from drones in many ways, but it's important to know what they can and cannot do before investing a large sum of money on equipment. The agricultural drone provider and coder Drone Deploy advises beginning small and progressively incorporating drone data into your company.

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CHAPTER 9

PERFORMANCE FACTORS OF AIRCRAFT MAINTENANCE PERSONNEL

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1. INTRODUCTION

Human Factors related training is foreseen as mandatory training by International Civil Aviation Organization (ICAO) and within the scope of Joint Aviation Requirements (JARs). This issue is taken into consideration in all processes from the design of the aircraft to the manufacturing phase and certification. The aircraft is designed according to human functions. All activities of the cockpit and cabin crew flying the aircraft and the technical teams maintaining the aircraft are based on human factors and it is aimed to prevent accidents caused by human beings.

Another aim of the training can be summarized as; to develop measures to reduce the causes of human error in maintenance by addressing the "human" dimension to those involved in aircraft maintenance and to help engineers to get to know themselves.

Today, approximately 28000 aircraft are in service in airline fleets around the world. In 2041, this figure is expected to exceed 40000 aircraft. Aircraft is the safest means of transport. However, accidents, albeit rare, can cause this confidence to be shaken. According to a study conducted by the Massachusetts Institute of Technology, the probability of a passenger dying in a plane crash is 1 in 8 million. This means that the risk factor is extremely low. Despite the low risk factor, when the causes of aircraft accidents are investigated, it is necessary to emphasize the question of how small mistakes create big disasters.

2. MAIN CAUSES OF AIRCRAFT ACCIDENTS

In the last quarter of the 1990s, statistics on the causes of aircraft accidents that occur in all jet fleets of commercial air transport airlines and result in fatal damage highlight that the rate of aircraft maintenance within the causes of accidents is around 6%. In other words, poor maintenance increases the accident rate by 6 percent, and if we evaluate the situation from this point of view, we can prevent 6% of accidents with good maintenance.

In the investigations carried out after accidents, when the facts are revealed, it is seen that a series of human errors, which we can define as a chain of events, were overlooked in the process leading up to the accident. If we can break the chain of errors during maintenance, accidents caused by this reason will not occur.

When the causes of accidents are investigated, it is observed that the factors that cause accidents have more than one "chain" effect. If one of the aforementioned factors is absent and/or the order of one of them is changed, in other words, if the chain of errors causing accidents can be broken, accidents may not occur. Therefore, in terms of flight safety, all weaknesses caused by maintenance problems must be known. Maintenance problems may occur in engines, landing gear, avionics systems, aircraft structure, components, as well as during ramp services. Due to errors, fatal accidents, accidents with serious damage, accidents that will occur over a long period of time, and accidents that will prevent airworthiness are possible. From another point of view, two important issues to be considered in aircraft maintenance constitute the main interest of aviation.

The first issue is related to old aircraft. In older aircraft, metal fatigue, corrosion, general wear and tear and obsolescence keep an intensive maintenance and technical control process constantly on the agenda.

The second issue is related to new aircraft. Due to the systems equipped with high automation, using advanced technology materials, more complex structure, requiring different test and control equipment to diagnose the malfunction, new aircraft bring different problems to the agenda. All maintenance personnel, especially technicians, need to be well trained. On the other hand, innovations and advanced technology, while providing convenience to the cockpit, impose more responsibility on maintenance (Torum, 2002).

3. AIRCRAFT ACCIDENTS AND MAINTENANCE PERFORMANCE

As it is known, the main duty of an airline is to transport its passengers, cargo and mail loads from point "A" to point "B" in the safest, most comfortable, most economical way and on time. The aim is to eliminate human error causes in this process. It is not possible to completely eliminate "risks" in any system. However, crises can be controlled and prevented through risk management. Managers decide on actions to be taken to prevent risks, crises or accidents within the framework of one of three possibilities (Federal Aviation Administration, 1997):

1. Complete elimination of the danger, removal,

2. Recognize the hazard and, based on the existing hazard, design and control the system to tolerate faults and reduce the probability of accidents,

3. If the hazard cannot be eliminated and controlled, learning to live with the hazard.

When a case study of an aircraft crashing due to icing during take-off is analyzed; in order to eliminate the hazard, no aircraft may be allowed to take off. In order to accept the hazard and take it under control, no flights should be made from non-de-icing airports and de-icing systems of the aircraft should be checked. If the hazard will be experienced together with the hazard; changes in training, supervision, personnel selection.

Increasing the number of warnings and making system changes to prevent errors. The factors affecting aircraft maintenance can be summarized as training, health, rules, information design (understandability and accessibility), equipment/design, materials, environment, production planning, union relations, associations, management relations, starting from the selection of suitable personnel. Today, human factors issues are concentrated on human / machine / environment relations. Systems can be integrated with work design, facility design, work stress, environment, and interaction in the workplace (Trollip and Jensen, 1991).

4. POTENTIAL ERRORS IN AIRCRAFT MAINTENANCE

It is useful to look at human errors in maintenance from this perspective. Errors occur in 2 ways in the model of faults caused by the technician and faults not caused by the technician. The first and most important of these are the faults that "do not exist" before the aircraft enters maintenance. The second type of faults are those that exist in the aircraft undergoing maintenance.

The most common errors encountered in maintenance could be classified as follows:

1. Incorrect assembly of components,
2. Installing the wrong parts,
3. Errors made in electrical cables,
4. Forgetting tools etc. on board the aircraft,
5. Inadequate lubrication,
6. Failure to detect cowlings, access panels, fairings,
7. Landing gear lock - pins not removed before take-off,

8. Fasteners are not fully fitted or torqued.

The most important issue stipulated by all systems and regulations is that the records of the transactions are kept as the transactions are made and without waiting. In simple terms, the basic rule can be summarized as "do what is written, write what you do".

5. FACTORS ADVERSELY AFFECTING AIRCRAFT MAINTENANCE

Sleep on night shift, weather conditions, time pressure, shift handover, employee morale, family problems, lack of manpower, airport safety, workload, bureaucracy/ red tape, co-operation/teamwork, contracts, deferred maintenance, interruption/interruption of work, lack of appropriate training, poor communication, equipment and procedures, forgetfulness, religious factors (Ramadan, Friday, holidays), collective bargaining periods, long holidays and political instability.

Work performance cannot be considered separately from life performance. When life performance is considered in a 24-hour unit, biological rhythm comes into question. Biological rhythm is a process adjusted to daytime. Sleep wakefulness pattern is the determinant of this rhythm. In addition, diet and social life are included in this rhythm. Biological rhythm directly affects work life (Torum, 2002).

On the other hand, individuals have two performances: actual and ideal. Actual performance is the totality of the effort and skill that can be shown under the current conditions of private and professional life. Ideal performance, on the other hand, is the maximum effort and skill that we can show when we can control the conditions in private and business life.

Achieving and maintaining optimum performance depends primarily on controlling the factors that affect one's performance. Therefore, physical fitness and health, sleep, workload, fatigue and stress should be emphasized.

The link between physical fitness and health also affects work performance. It is not correct to limit physical performance only to sports. Keeping physical performance high has a wide range from running to gardening. It depends more on the subject of interest of the person. The important thing is to do it continuously. Especially for shift workers, outdoor activities such as fishing and walking are very effective in controlling sleep problems. Solving riddles, engaging in brain teasers, playing games such as chess and bridge are also among the sports that provide brain activity.

Another important performance factor is "stress", "tension", which is the way the body responds to the lifestyle. If there are more stress-increasing factors in the lifestyle, tensions will also increase. However, stress is one of the indispensables of life. If it is completely eliminated, it has biological and psychological consequences almost equivalent to death. It is necessary to put aside the negative view of stress in life and to live with stress and to develop methods of controlling stress before stress takes control of the person.

Stress sources are divided into two as physical and social. In this sense, while the physical sources could be listed as hot/cold, noise, poor working conditions, lack of equipment, and traffic (apron, air traffic, city traffic), the sources of social stress could be economical (inflation, unemployment), political, family, work and career (urgent work, division of labour, competition, education and social environment), and education as a realization (ICAO, 1998).

Especially when we say stress sources for aircraft maintenance, time and urgent work are encountered. The symbol of the aviation industry is speed. Undoubtedly, when safety and security of human life are added to this, time pressure and speed become the main source of stress for maintenance workers. Such a working environment is a natural source of stress, and when shift work is added to this, when it is aggravated by insomnia and fatigue, a picture that must be controlled is encountered.

People who have healthy close relationships, who are in control of their lives, who have internal discipline and who like to fight, are able to cope with stress and live with it more easily.

Living with stress may lie in simple daily solutions such as listening to favorite music, shopping, walking or jogging, travelling. One of these simple solutions is to take short breaks, especially at work, to first take a break in thought, then take a look at yourself, try to clear your emotions, think about the subject again and take action.

There is a very close relationship between stress and performance. In periods when stress is too little or too much, performance cannot be at the desired level. Stress first stimulates the employee positively and reaches the ideal level for a while, but when it gains continuity, there is negativity.

We may have to use the given time in a hurry. The pressure of time may increase when carrying out an operation related to the maintenance card. However, there is always time "on the ground". The timetable, passenger needs and the economy of the operation are time dependent.

Many people gain the motivation to finish a normal job by thinking about time constraints. In other words, "time" is a positive parameter that ensures completion. When the time starts to shorten, when the time allocated for the task cannot be used well, when other tasks intervene, negative effects begin. In other words, the stress of not being able to finish starts. The body starts to react against stress.

To reduce the negative effects of stress in a race against time, it is necessary to recognize warning signals. Fast talking, completing sentences quickly without waiting for others to finish speaking, eating food faster, fussing while waiting in a queue, worrying that you will never get the work done, not being able to schedule it even though there is enough time, feeling nauseous while getting things done, feeling bored while doing work, driving the car faster, driving slowly symptoms such as anger at behavior are alarm signals.

As partially mentioned above, shift work is one of the factors affecting performance. Disturbances in sleep patterns, stomach disorders caused by eating habits during night shifts, and stress caused by incompatibilities with social life can have a serious impact on work if measures are not taken.

Sleep is a periodic phenomenon that occurs almost every day at the same time. Sleep is not a break from wakefulness. Sleep is also recognized as a habit. It usually starts at the end of the day and lasts 6 - 8 hours. Minimum sleep is considered to be 4, maximum sleep is considered to be 11 hours. During sleep, all organs of the body switch to listening mode. Body temperature decreases. Body temperature is an excellent biological clock. The biological clock of nocturnal people is behind and the biological clock of daytime people is ahead. These differences are tolerated on working days, but on holidays, the evening bedtime and morning wake-up times are pushed forward as far as possible. It is almost like a war against sleep. In fact, sleep deprivation is a serious fault and stress factor. A good and quality sleep has a positive effect on concentration, learning, memory and emotional balance.

Insomnia occurs when there are changes between sleeping and waking hours. On the other hand, physical and mental fatigue, stress and health problems can also cause insomnia.

Fatigue is a condition caused by prolonged physical or mental labor exceeding a certain limit, resulting from lack of rest. Fatigue is inversely proportional to the effort required for the work to be done.

Muscular fatigue or physical fatigue is objective and can be measured. In the case of mental fatigue, emotional stress is experienced despite normal rest. Mental fatigue is subjective and cannot be easily measured. Disruption of the body rhythm by fatigue is an important source of error. Excessive fatigue is also experienced after long-term tasks or tasks that are expected to be performed in a shorter time than necessary. It is divided into acute and chronic.

Acute fatigue is experienced briefly after intense physical or mental activity and disappears after a good night's sleep.

Chronic (inveterate) fatigue, on the other hand, takes a long time to develop and disappear. It is characterized by decreased attention, memory impairment, indifference in attitudes and introversion. The conditions for getting out of fatigue and going into a state of rest are also not well known. Sometimes it is possible to be tired even after adequate sleep (Trollip and Jensen, 1991).

Another factor affecting performance is whether the workload is too high or too low. Very long working hours will create stress in the employee and the risk of making mistakes will increase, especially if there is a lot of important work that needs to be concentrated. The level of mental and physical fatigue will increase.

On the other hand, low workload also creates tension. Purposeless leisure time emerges and creates habits in the employee. Work commitment can have consequences ranging from preventing the desire to put forth success and struggle to recklessness and disturbing the peace of work.

Nutrients are known to be an influential factor in human behavior and performance. For example, protein, fats and refined sugars can cause restlessness, low alertness, indecisiveness, irritability and a tendency to fall asleep.

Coffee, tea, rich sauces, spicy meats and overcooked foods. They affect the nervous system and increase the speed of metabolism. Diet is also important in the fight against fatigue.

Alcoholic drinks are energizing. They enhance physical activity but also increase emotionality. Alcohol has negative effects on vision and hearing, short and long-term memory. It impairs judgement and thinking. It weakens reflexes. It impairs coordination of movement. Worse still, it alters one's perception of oneself and emphasizes feelings of overconfidence or over-insecurity.

Depending on the type and amount of food taken in, the person sometimes feels heavy, lazy and sometimes feels energised. Some suggestions in this regard are listed below:

1. Instead of eating a lot of food in a few meals before or during a shift, it is preferable to eat more often but less frequently.

2. For shift workers, eating small meals in the hours before heavy physical work is also a dietary strategy.

3. Preferred carbohydrate-rich foods taken before or during a shift should contain slow-burning carbohydrates (e.g. brown rice, oranges, beans, grapefruit, milk, yoghurt, apples, nuts).

Good nutrition is very important for working performance. If you are on a diet, you should never go hungry and start your work day full. When people drink too much caffeine and theine, such as coffee or tea, it increases nervousness and tension and decreases reaction time.

It is very easy for people to use tranquillizers. Although these may provide temporary comfort, if the main cause of poor performance is not eliminated, they will not have any effect and may also be habit-forming. If habits such as drugs, alcohol, tea, coffee or cigarettes are replaced by physical fitness activities, the positive effect on health will be observed more easily.

As a result, many of the factors affecting performance will help production and ideal performance in line with the capacity in both private and business life with simple measures that can be taken in daily life (balanced nutrition, continuous activities, etc.)

6. CONCLUSIONS

All in all, the performance factors of aircraft maintenance personnel play a crucial role in order to ensure airworthiness as well as overall operational integrity of air vehicles. The maintenance personnel should be proficient and shall perform duties only in the areas of their competence. They shall have a clear understanding of aircraft systems, components, and maintenance procedures, so that they can detect potential issues. In doing so, they should adhere to regulatory frameworks. Last, but not least, the performance of aircraft maintenance personnel is directly related to their well-being, including sleep, insomnia, fatigue, workload, diet, nutritional habits, time management, and stress. Through prioritization of such factors could easily be expected to contribute a healthier and more effective workforce, and hence, improving safety and reliability in the aviation industry.

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CHAPTER 10

FOOD SAFETY AND QUALITY IN AVIATION

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1. INTRODUCTION

The airline catering industry is a sector located at the intersection of two important sectors, food and aviation, and the unique rules and implementation styles of both sectors are important in themselves (Kopsch, 2012). This situation, where two different disciplines coexist, provides great convenience for consumers and contributes to product development processes for the airline industry (Hsiao and Hansen, 2011).

While airline catering businesses are businesses that include services that will enable the creation of in-flight services, catering companies are known as businesses that allow food and beverages to be made ready for consumption within a central management (Sezgin and Özkaya, 2014; Ross, 2014). In the aviation industry, airline catering establishments and catering establishments have a significant impact on the provision of catering services. Therefore, airline companies, airline catering companies and catering companies provide services in close cooperation with each other in terms of the sale of the product in question and the satisfaction of the consumer who purchases the product (Salsa, 2012).

The concept of airline catering is defined as all kinds of food and beverage services that are attractive to passengers who prefer air transportation. Airline catering establishments provide two different types of services: services provided in the terminal and food and beverage services offered in the aircraft. The services provided at the terminal include self-service, technologically based service models or services provided through waiters and service employees. The concept of food and beverage service offered on board includes catering activities as well as food and beverage marketing activities (Koç, 2015).

The operating characteristics of airline catering businesses differ due to the nature and quality of the products produced, hygiene and compliance with standards, as well as the characteristics of the area in which they operate (Moskvitch, 2015). In addition, the fact that flights at high altitudes cause changes in taste and appetite distinguishes the production method of airline catering businesses from other businesses. The pressure, dry air and decreased oxygen experienced during high altitude flights can cause significant differences in consumption habits, such as loss of taste and appetite (Zahari et all, 2011). Studies have shown that during high altitude flights, the sense of taste and smell, which develop depending on normal consumption habits, decrease by 30% for every 10,000 meters altitude (Piqueras and Spence, 2014). In this sense, in-flight catering establishments should produce in-flight treats that are more salty or spicy than necessary, in order to ensure that the prepared treats are at a satisfactory level for the consumer, avoid producing foods that will cause digestive problems due to dehydration during the flight, and replace difficult-to-digest foods with foods that are difficult to digest. Producing easy, low-portion treat foods is among the measures taken (King, 2001; Jones, 2004). The primary precaution to be taken is the complete implementation of food safety standards. In this sense, by creating real kitchen areas on the ground in order to cook in-flight refreshments in accordance with the standards, the meals cooked in accordance with the number of people and their characteristics to be delivered to the plane are cooled or frozen with shock systems under appropriate conditions, thus preventing the development of microorganisms. (Ross, 2014; Lee and Ko, 2016). In-flight treats, which are prepared for consumption under appropriate conditions in the production area, are brought to the catering stage after short processes such as heating, thawing and placing in presentation tools in the aircraft (Pilling, 2001).

The catering planning stages are achieved through important information coordination such as flight plans, reservation numbers, special passenger requests created between airline companies, airline catering establishments and contracted catering establishments. The consumer products to be prepared are created according to the aircraft type, flight duration, flight type, general consumption habits of the population served, and aircraft take-off and landing time information included in the return information provided by airline companies (Yabacı, 2018).

2. IN-FLIGHT CATERING SERVICE AND ITS HISTORICAL DEVELOPMENT

Businesses that provide services to meet the food and beverage needs of individuals outside their homes are called catering businesses, and a service sector that plans and carries out the nutrition of a certain group from a center and delivers food and beverages ready for use to the end user is called catering service (Sezgin and Özkaya 2013). Although the catering industry has always operated in a wide area, it has increased greatly in both size and range in recent years (Farber and Todd, 2000). The flight industry, which plays a major role in transporting people or products to domestic or international lines, especially to regions where distances are long, has an important place in the economic development of a country. As the airline market has become much more challenging and competitive, providing high quality service to passengers has become one of the basic conditions for the profitability and sustainable growth of the airline (Archana and Subha, 2012). In-flight catering, which has been available since the first day of passenger flights, is a major industry serving more than 1 million passengers per day (Jones, 2004).

In in-flight food and beverage service, the number of special menus prepared or purchased by the catering company has increased over time, due to the effects of pressurized cabins on sensory organs and passenger psychology, as well as issues such as consumers eating in narrow spaces and storing food on the aircraft. With the increasing number of products, the ability to track needs such as loading these products onto planes and storing prescriptions has brought into consideration the necessity of using electronic production planning systems. Alpha Flight Services, one of the largest flight catering companies, has developed a system called Flight Catering Management System and can easily manage stages such as stock and production tracking, storing recipes, and product development processes (O'Hara and Strugnell, 1997).

In-flight food and beverage service dates back to the zeppelin flights of 1914. Since 1920, dining rooms were established on zeppelins and hot meals prepared by chefs were served to passengers (Jones, 2004). KLM, the world's first airline to use aircraft, started offering packaged meals on its London-Paris flights on October 11, 1919 (O'Hara and Strugnell, 1997; Jones, 2004). The first recorded full in-flight meal service was provided by AirUnion on July 30, 1927. This service was discontinued in June 1929 because the aircraft used (F-60 Goliath) were inadequately equipped for this type of service (Jones, 2004). In 1928, PanAm, an American airline, started to provide restaurant-like in-flight service on its planes by hiring uniformed cabin crew, while Western Airlines at that time began to serve meals obtained from restaurants to its guests (Dana, 1999). The first full hot meal service took place on Sunday, April 29, 1928, when Lufthansa introduced its new service, the 'Flying Dinner Car', on its 15-passenger B-31 model aircraft flying between Berlin and Paris. The B-31's fully equipped kitchen allowed the cabin crew to prepare and serve hot meals (Jones, 2004). As routes began to lengthen in the 1930s, airline companies began to serve hot meals stored in insulated boxes to their passengers. Later, airplanes were equipped with a kitchen system that allowed meals to be heated upon order during long flights (Dana, 1999).

3. CHARACTERISTICS OF FLIGHT CATERING SERVICE

In-flight food and beverage service begins with understanding the number of passengers and their needs, and airlines – sometimes with suggestions from suppliers and catering companies – develop service and product features such as which food, beverages and equipment will be carried on which routes, which class and passenger will be served at what time (Grothues, 2006; Jones, 2004).

The transfer of products takes place with special loading trucks that allow service cars to be easily transported in and out of the aircraft. After the products are loaded onto the plane, service carts and other products are stacked in the relevant places. When the predetermined time comes, the cabin crew serves these products. When the flight is over, all loaded equipment is taken back from the aircraft and transferred back to the production unit for reuse after cleaning. In order for this process to work flawlessly, it is necessary to understand the impact of flying on passenger physiology and psychology, to manage a complex supply chain, to ensure the safety and quality of products, to use increasingly sophisticated electronic information and communication technologies, and to play an active role in R&D studies (Jones, 2004).

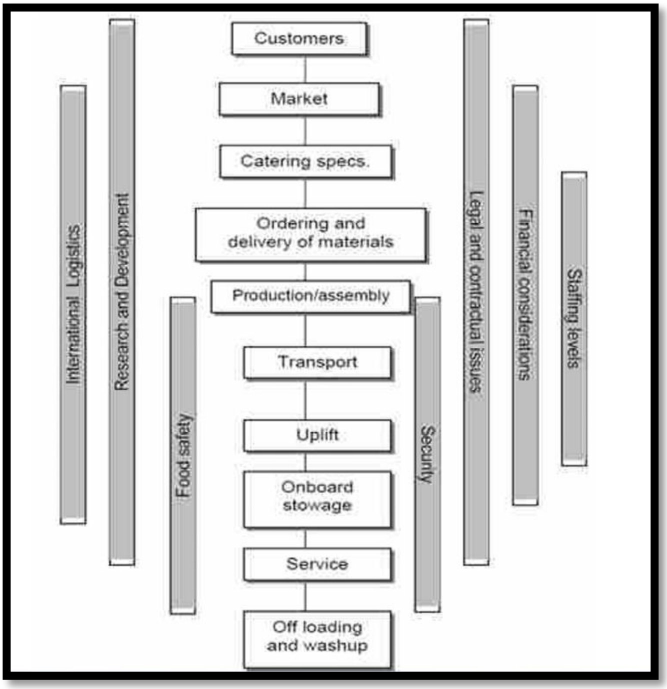

Figure 1. Flight Catering System (Jones, 2004)

4. FOOD SAFETY MANAGEMENT SYSTEM

Food safety is one of the basic requirements in airline catering systems. Food safety management systems provide a structured approach to ensure that precautions are taken to eliminate physical, chemical, biological and all kinds of damages that may occur in foods and to show the necessary care. A food safety management system consists of two components:

- Responsibility: A food safety management system should include details of positions responsible for ensuring food safety at each stage of the food chain and the limits of their responsibilities. Senior management is ultimately responsible for food safety. System details should be documented, communicated to the organization, and updated when changes are made to the company structure (Jha, 2020).
- HACCP (Hazard Analysis and Critical Control Point): The HACCP system is the operational and moral responsibility of airline companies to provide safe food to prevent food poisoning and contamination of passengers or crew to consumers. For this purpose, the HACCP (Hazard Analysis and

Critical Control Point) approach, an internationally accepted management system in which biological, chemical and physical hazards in food are analyzed and controlled at various stages such as production and production, was implemented in 1993 (Jha, 2020).

Airline catering services providers ensure the production of microbiologically suitable foods by adhering to HACCP principles. With the HACCP system, the industry, procedures and quality of raw materials used to provide as safe food as possible and ensure quality have been standardized, and safety measures have been provided to food processors to minimize the possibility of contamination. It is also observed that the importance of HACCP in providing safe food has increased since 2008. However, in ensuring food safety, in addition to the HACCP system, other factors such as hygiene and sanitation, pest control, traceability and recall in the field and in food need to be developed and implemented to prevent the risk of food poisoning and foreign bodies during processing (Tayar, 2010).

The application of HACCP principles consists of the following tasks as identified in the Logic Sequence for Application of HACCP in the Codex Alimentarius 1997.

Assemble HACCP Team Each responsible party should ensure that the appropriate product specific knowledge and expertise is available for the development of an effective HACCP plan. Where such expertise is not available on site, expert advice should be obtained from other sources. The scope of HACCP plan should identify which segment of the food chain is involved and the hazards to be addressed.

Describe Products: A description of the product groups should be drawn up, plus relevant processes such as handling, packaging, storage and distribution.

Identify Intended Use: The intended use should be based on the expected uses of the product by the end user or consumer. In specific cases, vulnerable groups of the population, e.g. institutional feeding, may have to be considered.

Construct Flow Diagram: The flow diagram should be constructed by the HACCP team. The flow diagram should cover all steps in the operation. When applying HACCP to a given operation consideration should be given to steps preceding and following the specified operation.

On-site Confirmation of Flow Diagram The HACCP team should confirm the processing operation against the flow diagram during all stages and hours of operation and amend the flow diagram where appropriate (Jha, 2020).

Implement the Seven Principles of HACCP Principles of HACCP

Airlines and Flight Caterers must demonstrate their HACCP system by documenting the relevant system elements HACCP Principles, these being:

Principle 1: Conduct a hazard analysis: The process of collecting and evaluating information on hazards and conditions leading to their presence to decide, which are significant for food safety and therefore should be addressed in the HACCP plan.

Principle 2: Determine the Critical Control Points (CCPs): A critical control point is a step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

Principle 3: Establish critical limit(s): A critical limit is a criterion, which separates acceptability from unacceptability.

Principle 4: Establish a system to monitor control of the CCP: Monitoring is the act of conducting a planned sequence of observations or measurements of control parameters to assess whether a CCP is under control.

Principle 5: Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control: Corrective Action is any action to be taken when the results of Monitoring at the CCP indicates a loss of control.

Principle 6: Establish procedure for the verification to confirm that the HACCP system is working effectively: Verification is the application of methods, procedures, tests and other evaluations, in addition to monitoring to determine compliance with the HACCP plan.

Principle 7: Establish documentation concerning all procedures and records appropriate to these principles and their application (Carol et all, 2018).

5. SUPPLY CHAIN

Supply chain is a complete system consisting of the production and delivery of a product or service, from the procurement of raw materials to its delivery to the consumer, and this chain includes all aspects of the production process, the activities to be carried out at each stage, the information that needs to be conveyed, the conversion of natural resources into useful materials, human resources and the finished product or includes other components that come into service.

A supply chain is a network between a company and its suppliers to produce and distribute a specific product to the final buyer. This network includes different activities, people, entities, information, and resources. The supply chain also represents the steps it takes to get the product or service from its original state to the customer. Airline companies develop this network to reduce their costs and remain competitive in the business area. It enhances production cycle faster (Jha, 2020).

6. FOOD STORAGE AND TRANSPORTATION

Food storage and transportation in the aviation industry is an important element in providing a safe and quality food service to passengers. This process involves storing, transporting and serving food in appropriate conditions throughout the supply chain.

Supply chain management: Airlines should work with reliable suppliers and carefully evaluate their supply chain processes before sourcing food products. Traceability and reliability of food must be ensured throughout the supply chain.

Storage conditions: Foods to be used on airplanes must be kept under certain temperature, humidity and other storage conditions. Certain storage standards must be followed to prevent food spoilage and ensure safety.

Cold Chain Management: Cold chain management is important, especially for fresh and perishable foods. It is necessary to maintain certain temperature ranges for the storage and transportation of high-quality foods.

Packaging and Labeling: Correct labeling and packaging of food is critical for both safety and quality of service. It is important to clearly state information such as food allergens, dates and ingredients.

Safety and Hygiene Standards: Food storage areas and transport vehicles must fully comply with hygiene standards. Cleaning and disinfection processes should be carried out regularly and precautions should be taken to minimize food safety risks.

Staff education: Personnel working in food storage and transportation processes should be trained on food safety and hygiene. Personnel who come into contact with food products should also observe proper personal hygiene practices.

Food Safety Controls: Food products should be checked regularly during storage and transportation processes. Foods that are spoiled, damaged or pose a safety risk should be identified and isolated immediately.

Traceability and Reporting: Airlines must ensure traceability of food products throughout the supply chain. Additionally, it must be able to report quickly and effectively in case of any problems.

Food storage and transportation in aviation is a complex area that must be carefully managed to ensure food safety and quality. Executing these processes effectively is critical for both passenger safety and the reputation of airline companies.

7. FOOD SAFETY CONTROLS

Food safety controls in aviation include inspections and controls to ensure the safe production, storage, transportation and service of food products. These checks are important to provide a safe and quality food service to passengers, to prevent foodborne diseases and to ensure the reliability of airline companies in general.

Supplier Reviews: Airline companies evaluate their food suppliers regularly. These assessments include the supplier's compliance with production processes, quality control systems and food safety standards. Working with certified suppliers is important at this stage.

Production and Storage Facility Inspections: Facilities where food products are produced and stored are regularly inspected. In these inspections, issues such as hygiene standards, personnel training, facility layout and suitability of production processes are reviewed.

Food Analysis and Tests: Food products are regularly tested for bacterial contamination, microbial safety and other quality parameters. These tests are performed to verify that food products are safe and of high quality.

Cleaning and Disinfection Controls: Food storage and transportation vehicles undergo regular checks for cleaning and disinfection. This ensures that hygiene standards are maintained and the risk of bacterial contamination is reduced.

HACCP Controls: Threat Analysis and Critical Control Points (HACCP) principles are part of food safety control processes. By applying HACCP principles, airline companies review food production processes and identify critical control points.

Traceability and Record Keeping: Food products must be traceable throughout the supply chain. Recording information such as where each product is produced, how it is stored and how it is transported allows quick detection of potential security issues.

Staff Training and Information: Food safety controls include training of personnel working with food. This means understanding hygiene practices, knowing food safety protocols, and being aware of potential risks.

Emergency Plans: Food safety checks include emergency plans. If a security issue arises, airlines must be able to respond quickly and effectively.

These controls and audits represent a comprehensive approach to ensuring safe and quality food services in the aviation industry. Airlines must keep food safety standards high by constantly updating and improving these controls.

8. EMERGENCY PLANS

Emergency plans in airline catering services aim to ensure a rapid and effective response to unexpected events or emergencies. These plans cover a wide range of issues, which may include food safety, hygiene, supply chain disruptions, natural disasters, epidemics or other emergencies.

Risk Analysis and Threat Assessment: Creating emergency plans begins with identifying potential risks and threats. This should include various elements such as the supply chain, production facilities, storage areas and transportation processes.

Communication Plans: Effective communication is critical in times of emergency. Communication plans should be developed to ensure rapid and accurate flow of information between relevant stakeholders. This includes internal staff, suppliers, airline management, and other relevant stakeholders.

Education and Awareness: All staff should be trained regularly on emergency plans and processes. This is important to ensure that personnel act correctly and effectively during emergencies.

First Aid and Emergency Response: Emergency plans should ensure that staff have basic first aid skills and can respond effectively in times of emergency.

Resource Management: Emergencies often involve situations where resources are limited. Plans should include strategies to effectively manage personnel, materials, and other resources.

Traceability and Reporting: During emergencies, food products must be traceable throughout the supply chain. Additionally, reporting should be done quickly and effectively in case of any emergency.

Security Protocols: Emergency plans should include safety protocols in facilities and transportation vehicles. This includes measures taken to ensure the safety of staff and facilities.

Epidemic and Pandemic Plans: Especially considering the recent global epidemics, companies providing catering services should have special plans that specify how to act in epidemic or pandemic situations.

Supply Chain Backup: Contingency plans should include how to prepare for supply chain disruptions and how to switch to alternative sources of supply.

Continuous improvement: Emergency plans should be reviewed and updated periodically. After every emergency, improvements should be made to the plans.

In airline catering services, emergency plans are critical not only for protecting facilities and food safety, but also for customer confidence and company reputation. Plans must be meticulously created and implemented to increase the ability to deal with possible emergencies and minimize their effects.

9. CUSTOMER FEEDBACK

Customer feedback in airline catering services is very important in order to evaluate passengers' experiences and improve service quality. Customer feedback provides airlines, caterers and other essential stakeholders with valuable information to understand how effective the service is and identify potential improvements.

Surveys and Forms: Airlines may offer passengers post-flight surveys or feedback forms regarding special meal services. These documents allow travelers to evaluate their experience and answer specific questions.

Online Platforms and Applications: Airline companies can provide their customers with the opportunity to evaluate services through online platforms or mobile applications. This allows passengers to provide feedback in comfort.

Social Media Tracking: Customer feedback can also be obtained through comments and reviews shared on social media platforms. Airline companies can monitor customer satisfaction and complaints by paying attention to feedback on social media.

Customer Communication Line: A dedicated customer contact line allows passengers to provide direct feedback. These lines play an important role in answering questions, resolving complaints, and improving overall customer satisfaction.

Focus Groups and Customer Interviews: Airline catering service providers may hold special focus groups or conduct customer interviews. This is an effective way to get direct customer feedback and provide more detailed understanding.

Feedback Analysis and Improvement Processes: Obtained customer feedback should be analyzed regularly. This analysis can be used to identify where service is strong in specific areas and areas with potential for improvement.

Customer Satisfaction Indices: Airlines can use various indices to measure customer satisfaction. These indices are useful to objectively evaluate service quality.

Quick Feedback Opportunities: Mechanisms can be established that allow passengers to provide rapid feedback during or immediately after the flight. This gives you the chance to measure instant satisfaction and make quick improvements.

Customer feedback is a critical tool for continuous improvement of airline catering services. By regularly focusing on customer feedback, airline companies can improve service quality, ensure customer satisfaction and gain competitive advantage (McMullan et all, 2007).

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