Matrix Materials Used in Composites

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***Abstract*— Metal matrix composite materials combine the properties of metal and ceramic materials, namely ductility and durability. Thus, they become suitable for material production with high strength and high service temperature. As an alternative to steels and non-ferrous alloys, due to their superior properties, composite materials exhibit extraordinary potential, especially in aviation, automobile industry and structural materials development.**

***Keywords*— composite material, non-ferrous alloys, aluminium, GNP**

I. INTRODUCTİON

Today, due to the increasing globalization and industrialization, the performances expected from materials, devices and machine parts produced by traditional methods are not sufficient. For this reason, research and development (R&D) activities on the development of high value-added, functional and high-performance advanced technology materials have gained momentum in recent years. Especially with the introduction of technology into human life, new generation materials have been produced in many industrial areas. One of these materials is composite materials [1]. Composite materials are formed by combining at least two different materials at the macro level (not dissolving in each other) and can be classified as polymer matrix, ceramic matrix and metal matrix composites (MMK) according to the matrix material.

Composite materials were developed mainly to improve the mechanical properties of materials with the emergence of the material as a science in the early 1960s. Composite materials take place in various fields of industry due to their physical and mechanical properties that combine industrial designs at the appropriate time and ensure product reliability. High strength, corrosion resistance, abrasion resistance, aesthetic properties, low weight, fatigue life, temperature-dependent behaviour, thermal insulation, thermal conductivity and sound insulation in composite materials recently used in ship and machine construction, aviation and space technologies, home and industrial buildings. features such as can be developed [2].

Composite materials basically used in the automotive, defence and aerospace industries. Especially in the automotive industry, aluminium matrix composite materials are preferred in the production of a wide range of product groups such as engine blocks, cylinder liners, pistons, brake discs and pads, gears, pumps and valves. Therefore, these materials are increasingly replacing the group of materials used before them. For example, while graphite alumina reinforced aluminium matrix composites are preferred for cylinder liners in engine blocks, brake drums previously made of cast iron have been replaced by those made of SiC reinforced Al matrix composites. Same way in the aviation industry; Al_2O_3 fiber reinforced Al matrix composite materials are used in the production of gear boxes, Bor-SiC fiber reinforced Al matrix composite materials are use in jet engine blades, and graphite fiber reinforced Al composite materials in helicopter and rocket parts [2-3].

Used as a matrix material in metal matrix composites, aluminium is the most consumed metal in the world after iron. The intensive use of this metal is due to its high formability, light weight, and a good conductor of heat and electricity. Today, aluminium and its alloys are used in many areas such as aerospace industry, automotive industry and construction industry. Graphene, one of the carbon-based reinforcing elements, is an allotrope of carbon, whose mechanical, electrical, thermal and optical properties have been newly discovered, and consists of honeycomb knitted structures of carbon. This structure is a single layer of graphite structure consisting of hexagonal cells. Also, graphene is a super-flexible, super-tough, super-light and super-thin material, considered one of the most exciting scientific advances available [4].

Metal matrix composites (MMC) are engineering materials formed by the combination of hard reinforcement phase in metallic matrix. MMCs are materials with more special features such as high strength, hardness and less dense properties. The matrix material of MMCs contains metals such as aluminium, magnesium, copper and alloys. Reinforcement materials; ceramic materials such as alumina, silicon carbide, boron nitride in the form of continuous fibers or non-continuous fibers / particles. These materials consist of a combination of two or more materials that show properties that are difficult to obtain from a single material. The matrix material both distributes the stress applied on the reinforcement components and gives the composite material its shape by protecting it. With the choice of reinforcement, the desired mechanical properties of the composite material are created and its strength is provided. The reinforcement element is in the form of wire, capillary crystal or particle and continuous or discontinuous fiber, and different percentage volume ratio distribution within the composite strengthens the properties of the composite [4-5].

II. MATERİAL AND METHOD

A. *Matrix materials of composite Style*

The Matrix materials are composites consisting of different metals and metal alloys and can be reinforced with different materials. In composite materials, the properties of the matrix and the reinforcement, the volume ratios and the properties of the bond between them affect the mechanical and physical properties of the produced composite. In addition, in composite structures, the matrix and the reinforcing element should not dissolve in each other. On the other hand, with a small amount of solubility, the formation of a bond between the matrix and the reinforcement can have a positive effect. The task of the matrix is to support the fibers in the composite material and hold them together. The loads on the composite are first met by the matrix and transmitted to the fibers through the matrix. It also ensures that the matrix fibers remain in the indicated direction and maintain their position. In addition, the matrix is resistant to environmental conditions and determines the resistance of the composite to the maximum temperature it can withstand. The most important point to consider when choosing the maximum service temperature of a composite is the use of a suitable matrix material. Types of matrix materials, depending on the intended use of the composite material and production techniques [5,6,7]. The classification of composite based on the matrix materials shown in Fig. 1.

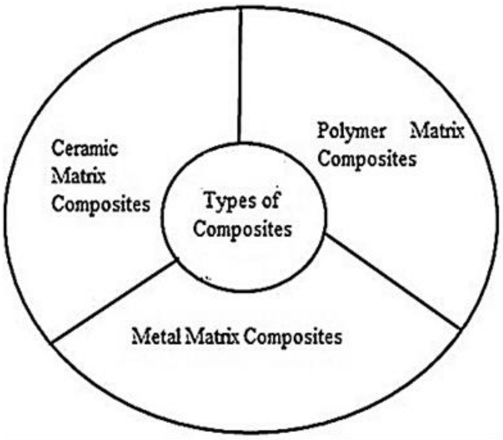

Fig. 1 Classification of composites according to matrix materials [6].

Background of the growth of metal and ceramic matrix composites is much more current than polymer matrix composites. Preliminary research on metallic and ceramic matrix composites failed to produce perfectly high-quality composites because they focused on durable carbon or boron fibers, and continuous development in the field of fibers has accelerated this research.

B. *Polymer matrix composites*

Polymer matrix composite materials were developed in the 1940s for use in the aerospace industry. The main goal in improving these materials was to obtain a material that was lighter but more durable, with higher hardness values and corrosion resistance. Polymer matrix composite materials are divided into thermoset and thermoplastic matrix. For the reinforcement of polymer matrix composite materials, more aramid, basalt, jute, carbon, coconut, glass, etc. are used as fillers. fibers are used [8].

The types of materials used in the production of thermoset matrix materials are epoxy, polyester, vinyl and phenolic resins. Most thermoset matrices must be stored frozen to prevent them from hardening. Thermoset resins do not dissolve under chemical influences and are long-lasting even in unusual weather conditions and cannot soften even at high temperatures [9].

Although there are many types of thermoplastic polymers, the polymers used as matrices are limited. Thermoplastics are hard at low temperatures and soften when heated. The thermoplastic, which is solid at room temperature, can be stored in the refrigerator without waiting. The main reason why thermoplastics are not selected as a matrix in composite materials is both high prices and difficulties in production. Thermoplastics, widely used in the automotive industry (Figure 2), are also used in high-performance material solutions in the aircraft industry

Fig. 2 Thermoplastic polymer matrix composite material used in the rear wing of the race car [9-10].

PMCs, the matrix generally reinforced with ceramic fibers since they have high strength in comparison of the matrix material. The characteristics of PMCs are relying on the matrix, reinforcement, process parameters, microstructure, composition and the interphase. PMCs are well-known for their reasonable price and the easy method of production. The manufacturers of PMC can create cost-effective products with various manufacturing procedures. Each manufacturing process has features defining the sort of product to be manufactured. This expertise enables the manufacturer offers the best option for the consumer. Lightweight is an important feature of polymers. Polymer composite composites (PMCs) offer a wide variety of properties. Some of them are high strength, excellent impact, compression, fatigue properties; cost-effective processes of production and tooling, outstanding chemical and corrosion resistance, available at low-cost chemical inertness and good mechanical characteristics [9,10].

C. *Ceramic matrix composites*

Ceramic Matrix Composites are a mixture of ceramic particulates, fibers and whiskers with a matrix of another ceramic and may be defined as solid materials that normally show highly strong bonding generally ionic, but in a few cases, it may be covalent. The ceramic matrix can be reinforced by ceramics, metals, glasses, and polymers. The ceramic-based matrix materials are having exceptional corrosion resistance, high melting points, superior compressive strength, and stability at high temperatures. Ceramic matrix composite materials are widely used in industry due to their high heat resistance and light weight. These composite materials are mainly used in areas with high temperatures. Ceramic materials are very hard and brittle. As a matrix material, SiC, Cr_2O_3, TiN, Si_3N_4, TiB, B_4C and TiC are the most widely used materials in ceramic matrix composite materials. Metal and ceramic nano powder are also used as fillers [11].

Ceramic materials are very attractive because they are resistant to high temperatures and light (d = 1.5 - 3.0 g / cm3). Ceramic matrix composite materials are generally used for parts that need to be operated at high temperatures. Ceramic materials, which are hard and brittle materials, show very low elongation during breaking, have low strength and are not resistant to heat shocks, so they are reinforced with fibers. However, they have a very high modulus of elasticity and very high operating temperatures. It is widely used in applications requiring high temperatures due to its advantages such as high heat resistance, chemical resistance, hardness, resistance to erosion and corrosion, and light weight. Ceramic matrices are the common choice for high-temperature applications such as pistons, blades, rotors in gas-turbine parts [12].

The principal goals in the making of CMCs are to enhance the toughness because monolithic ceramics are brittle but having high stiffness and strength. It is crystal clear that the reinforcement along with particulates and continuous fibers, has led to a rise in toughness, but the rise is even more considerable for the second, CMCs either oxide-based or non-oxide based, a comparison of modulus of elasticity of few ceramics shown in Fig. 3.

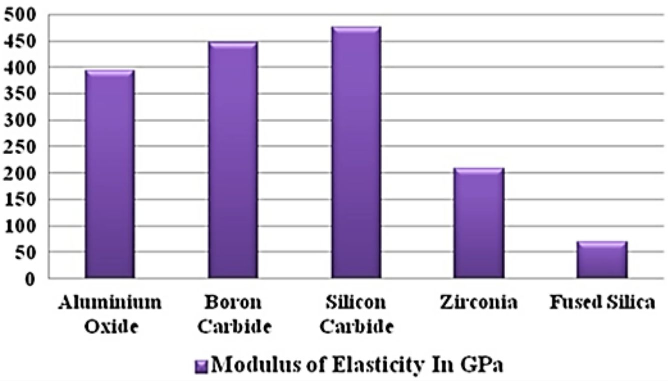

Fig. 3 Modulus of Elasticity of ceramic materials [13].

D. *Metal matrix composites*

Metal matrix composite materials were developed in the early 1960s because of the need for materials with higher specific strength properties that could be used at temperatures higher than the current temperature of existing materials. Metal matrix composite materials are manufactured by combining two or more different materials, at least one of which is metal, at the macro level to provide the desired and required properties. Polymer, ceramic and nanomaterials are mostly used as filler materials in metal matrix composites [14].

It should be noted that metal matrix composite materials have a higher ability to work in high temperature areas than polymer and ceramic matrix composite materials, the probability of combustion at high temperatures is very low and their service life is longer. Compared to fiberglass-reinforced plastics, metal matrix composite materials are much better at high temperatures. The strength and elastic modulus of metal matrices are higher than resin matrix materials over a wide temperature range.

The predominant matrix materials in composite materials are light metals and alloys with low density, high strength and good mechanical properties. These light metal alloys are especially preferred in lightweight structures where weight is at the forefront due to their good strength and specific gravity ratios.

In general, metals such as aluminium (Al), magnesium (Mg), zinc (Zn), copper (Cu), titanium (Ti) and nickel (Ni) and their alloys are widely used as matrix materials in the production of metal matrix composite materials [5,15]. Diagram of the use of metals in composites on the world market shows in Fig. 4.

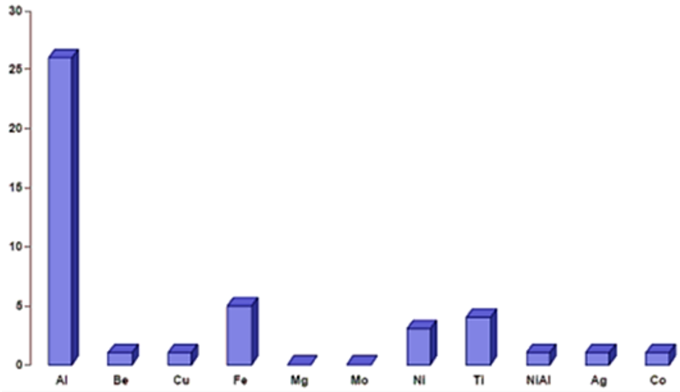

Fig. 4 Diagram of the use of metals in composites on the world market [5,15]

Al and Al alloys are the most commonly used matrix materials in the production of metal matrix composites. Al is rich in nature, easy to process, lightweight, has important properties such as corrosion resistance and durability. Alloys are preferred because they are lightweight, can be produced cost-effectively by many production methods, and have high strength and corrosion resistance.

Composites based on titanium have a vast application, especially as a material for high-temperature structures. Alloys of titanium are typically used in the aerospace components because of superior strength at high temperature and good corrosive resistance. The material, however, is expensive. Magnesium is the lightest out of a range of non-ferrous metals, generally used in electronics equipment, the chain saw housings and gearbox housings for aerospace applications. Copper can be easily cast and formed. Copper-based composite materials having excellent wear resistance and are used in electronics as electrical contacts and elements of the electronics system [13,17]. Mechanical properties of some metals which generally used as a matrix are shown in Fig. 5, Fig. 6, Fig. 7.

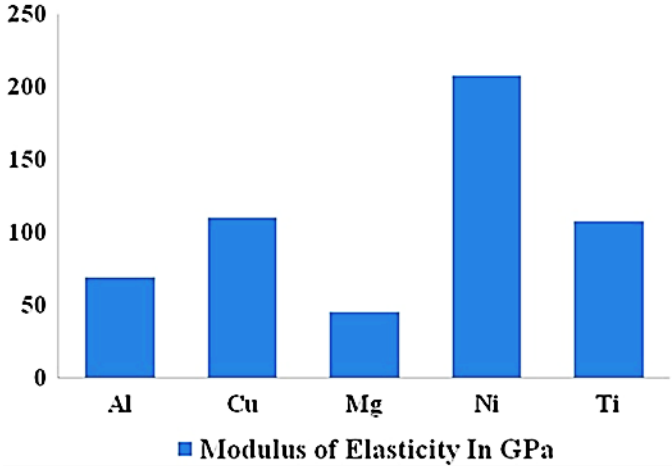

Fig. 5. Modulus of elasticity for different metals normally used as matrix material [13-17].

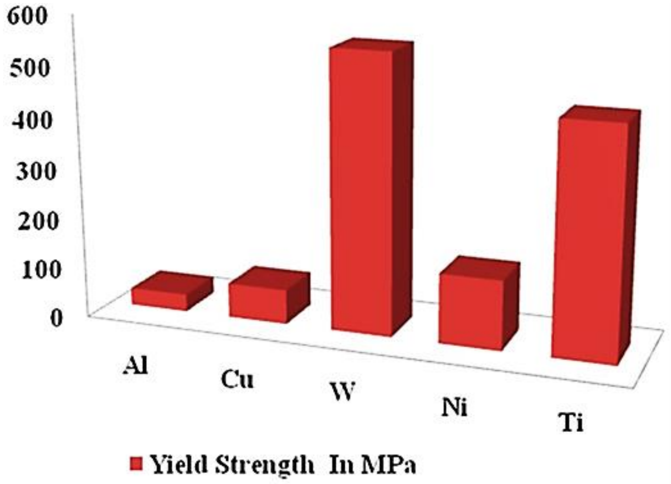

Fig. 6. Yield Strength of metals generally used as matrix material [17].

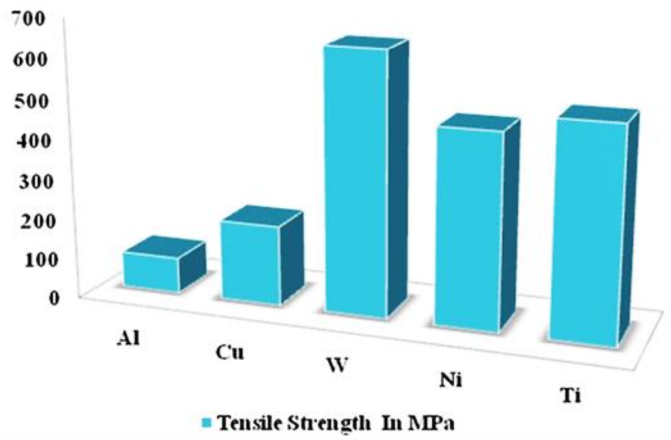

Fig. 7. Comparison of Tensile Strength of metals commonly used as matrix Materia [13-17l.

E. *Al matrix composites*

Al and its alloys are generally used for producing MMC. In most of the engineering applications, Aluminium and its alloys grabbed the attention most as matrix material in MMCs due to their outstanding mechanical properties, excellent ductility, and good corrosion resistance. Aluminium matrix composites are familiar due to their easy availability, low-cost and attractive wear resistance. Al-MMCs are widely used due to the combination of factors such as durability, machinability and accessibility than other competing materials (Fig. 8) [18,19,20].

Production of metal matrix composites accounted for 14% of the aviation industry in terms of trade in the early 2000s.nThe first discovery of the metal matrix composite was made to increase interest in the aerospace industry to meet high performance requirements. Metal-matrix composite materials in the aerospace industry find applications in rocket, satellite, aerospace and helicopter parts, parts in close contact with electricity, batteries, jet engine fan blades, antenna designs, reactors, high-temperature engine parts and high-temperature structures [21].

Fig. 8. Different applications of aluminum MMCs in industries [18-20].

For example, the fuselage wings of F16 aircraft, which were mainly problematic, were replaced with SiC-reinforced metal matrix composites, which extended their life and saved about $ 26 million. The back of the trunk wings is shown in Figure 9. In addition, in the past, the service life of the bottom covers was improved 4 times by using 17.5% SiC ceramic-reinforced Al 6092 metal matrix composite instead of the bottom covers of the body made of 2024-T4 Al alloy.

Fig. 9 The rear body wings of the F16 are made of Al matrix composites [22].

The automotive industry is a field that works with advanced technology and has a very high production capacity. It should be ensured that costs in the automotive industry are not as high as possible. Areas of application of metal matrix composite materials in the automotive industry include: piston ring, piston combustion chamber, engine block parts, cylinder inner face and stock.

The first application of metal matrix composites in the automotive industry was in 1983 on diesel pistons of Toyota cars. In the following years, the Honda car company produced cylindrical liners from metal matrix composites to provide 12% Al2O3 ceramic corrosion resistance as a reinforcing element. In addition, Honda has developed a high-pressure casting method to reduce the cost of building engine blocks [22].

F. *Graphene reinforcement Al matrix composite*

The extraordinary thermal, mechanical and electronic properties of graphene have made graphene an important reinforcing element in composite production. In addition, the fact that graphene reinforcement is quite low compared to other known composites and these extraordinary properties of graphene are the most important reasons for preference. In addition to making the composite lighter with simple processes, graphene can make the composite more resistant for multi-functional applications. The effect of these remarkable superior properties of graphene on the composite depends on the homogeneous distribution of graphene in the matrix. As shown in Figure 10, the modulus of elasticity of graphene is approximately 100 times higher than steel and is a better heat conductor than diamond, another carbon allotrope that is thought to conduct heat well [23,24].

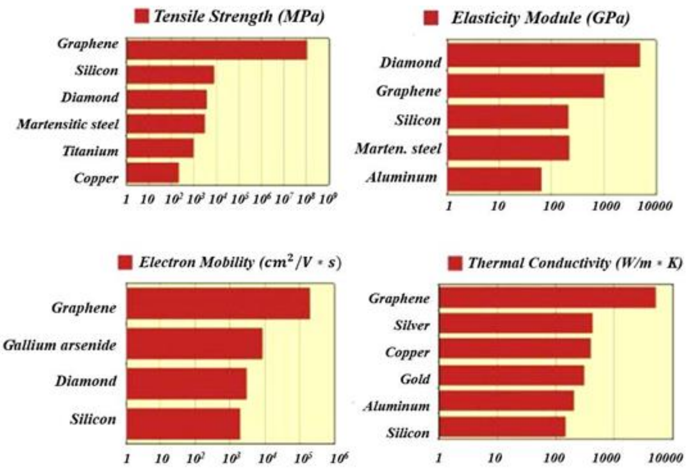

Fig. 10 Comparison of various properties of graphene with other known materials [23]

The fact that graphene is in the form of a nano-layered (GNT) plate provides easy processing and homogeneous distribution of graphene in the matrix. Therefore, GNT / Al composites, CNT / Al composites is an alternative composite structure instead. The homogeneous distribution of graphene in the metal matrix is the most important parameter in achieving the desired strength in the composite structure. On the other hand, the metal matrix and the carbon-based material should not react. When an Al-based metal reacts with carbon, $4Al + 3C = Al_4C_3$ is formed, so the reaction of the carbon with the metal must be prevented. Another important issue is the wetting behaviour of metal and graphene. Especially wettability between liquid and solid surface is very important in terms of interface bonding. For this, the surface free energy must be minimum [25,26]

General production of GNT / Al composite structure consists of four main stages.

1) dispersion and modification of graphene in metal matrix,
2) grinding and shaping aluminium with graphene,
3) subjecting the composite structure to heat treatment, hot rolling and extrusion processes,
4) characterization of the structural properties of composites produced [27].

Since graphene was a material that was first synthesized in 2004, graphene was used as a reinforcement element in the composite structure after 2008. In scientific studies published in this field, it has been determined that the use of graphene in the composite structure improves the mechanical properties of the composite. In these studies, it was determined that the graphene reinforcement used by weight in the composite structure varies between 0.1-3%, and after 0.5% by weight, the graphene tends to clump and undesirable secondary phases such as Al_4C_3 may form [28,29].

When the SCI indexed studies in the literature are evaluated, the effect of the amount of graphene on the mechanical properties of Al composite is given in Figure 11a. Here, the maximum tensile strength of pure aluminium is approximately 155 MPa, while it increases up to 315 MPa with 0.5% graphene by weight [30]. On the other hand, a decrease in the maximum tensile strength is observed after 0.5% graphene contribution by weight. In addition, graphene can be used as a reinforcement element on Al alloys and Al-ceramic composites instead of pure Al. When used as an alloy, the tensile strength increases from 350 MPa to 800 MPa [28].

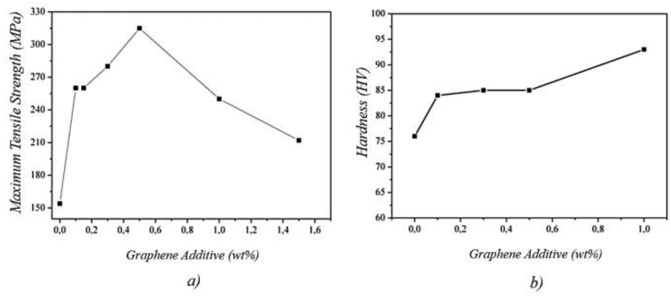

Fig. 11 a) Graphene additive to tensile strength of Al composites and b) effect on hardness [28-30]

In Figure 11b, it is seen that the Vickers hardness value of unadulterated Al is 76, while the hardness increases with the increasing amount of GNT. It was determined that by using 1% GNT by weight, the hardness value increased up to about 94 [29]. However, after 0.5%, the probability of formation of the Al_4C_3 phase increased depending on the increasing amount of graphene. Therefore, the composition most studied in the literature are 0.3% and 0.5% by weight graphene reinforced aluminum composites.

Conclusions

As a result of the literature studies, it has been seen that aluminum matrix composite materials are light potential engineering materials with excellent properties within the metal matrix composite material group.

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