

# The effect of nanoparticles on enhancement of the specific mechanical properties of the composite structures: A review research

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**Abstract.** In this review, composite structures are used for many industries for at least four decades. Polymeric composites are one of the important structures in the aerospace and aviation industry because of their high strength and low weight. In this comprehensive review, mechanical behaviors, physical and mechanical properties of polymeric composites, different types of reinforcements, different methods to fabricate polymeric composites, historical structural composite materials for aviation and aerospace industries, and also different methods for the characterization are reported. How to use various methods of composite preparation using different nanofillers as reinforcements and its effect on the physical properties and mechanical behavior of composites are discussed as well.

**Keywords:** aerospace industry; reinforcement; composites structures; mechanical behavior; physical properties

## 1. Introduction

In the last four decades, the use of composite structures in the aerospace and aviation industries have become more widespread (Hejri *et al.* 2020). The properties of composite materials are comparable to those of metallic coatings and metals (Nejadi and Mohammadimehr 2020). Composites are so efficient that they are used in aircraft and spacecraft components (Tayeb *et al.* 2020). From hot air balloons and unmanned aerial vehicles to passenger and warplanes and space shuttles, all benefit from the composites (Shahsavari *et al.* 2019). Therefore, the use of composite structures in the aerospace industry from 2005 to 2020 has grown more than 400% (Ahmed *et al.* 2014). Composites are among the most widely used products in structural components and aircraft parts because of their high strength, little specific gravity, abrasion resistance. Researchers have long sought to reduce the weight of aircraft to prevent crashes, and they have always sought to reduce the ratio of thrust to weight to reduce the risk of crashing (Mehar and Panda 2019). Composite structures are utilized in numerous industries such as aerospace industries. The use of new technology in the production of innovative ideas and products has accelerated with the achievement of the basic structure on a nanoscale (Farazin *et al.* 2019, 2020). Today, metals and other materials are used to help humans to improve their quality of life. Today, due to the significant advances in the use of composite materials, the current time can be called the composite era. Types of composite materials have been examined for many years for significant industries such as

aerospace applications (Arani *et al.* 2019, Ghorbanpour Arani and Soleymani 2019, Soleymani and Arani 2019, AkhavanAlavi *et al.* 2019). Many polymers are reinforced with various nanomaterials to develop and enhance their attributes in addition to enhance their applications (Anvari *et al.* 2020, Mohammadimehr *et al.* 2015, 2016, 2017, 2018a). Examining nanotechnology, many nanomaterials are used as nanofillers to make nanocomposite. Polymers are used as a matrix in composites, and they are separated into three types using the size of the fillers as reinforcement in the composite structures (Arefi *et al.* 2018). Type 1: when a two-dimensional material that is the same as the sheet structure is used as a nanofiller such as graphene platelets (GPLs) (Arshid *et al.* 2020, Rajabi and Mohammadimehr 2019). In two-dimensional fillers, one of its dimensions is at the nanoscale and the other is at the microscale (Ghorbanpour Arani *et al.* 2018). Type 2: in these structures, two dimensions are at the nanoscale and another dimension is at the microscale, thus these structures become a one-dimensional material (Mohammadimehr *et al.* 2018b). These are cylinders such as carbon nanotubes (CNTs) and nanofibers (Ghorbanpour Arani *et al.* 2016, Navi *et al.* 2019). They are very useful for improving polymer resistance (Ghasemi *et al.* 2019). Type 3: in these structures, three dimensions are at the nanoscale, thus, they are the zero-dimensional material. Also, they are like quantum dot particles (QD), quantum clusters (QC), and so on. Also, anchor polymer has excellent thermal and physical properties because of its high level of composition per unit volume. Babaeian and Mohammadimehr (2020) investigated the time elapsed effect on residual stress measurement in a composite plate by DIC method. Moreover, the relationship between anchor polymer (matrix) and fillers is defined as follows (Fu *et al.* 2019)

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$$R = \frac{3000v}{r} \quad (1)$$

where  $v$  and  $r$  are the volume fraction and the radius of nanoparticles, respectively. In this comprehensive review study, mechanical behavior, physical and mechanical properties of polymeric composites, various types of reinforcements, a different method to fabricate polymeric composites, historical structural composite materials for aviation and aerospace industries, and different methods for their characterization are presented.

## 2. Significant polymer utilized in aviation and aerospace industries

Thermoset and thermoplastic polymers are the two main types of polymers for aerospace and aviation applications. Thermoset polymers can withstand high temperatures, and also they are difficult to convert into liquid or powder. Thermoset polymers have high strength, and due to the complex interconnection, they have sufficient stability at high temperatures. Thermoplastic polymers are soft, flexible, and also lose their properties at higher temperatures. Thermoplastic polymers have fewer applications than thermoset polymers due to their high viscosity (Khandan *et al.* 2020). Frequently used thermoset polymers are including phenolic, vinyl esters, polyesters, epoxy, and polyurethane resins. Recently various types of reinforcements (fibers) have been utilized in macro, micro, and nanocomposites. In this comprehensive review, various fibers are introduced including glass, carbon, basalt, aramid, and natural fibers that are practical in the aviation and aerospace industries (Khater 2016, Masalov *et al.* 2014).

### 2.1 Glass fibers

Glass fibers have been widely used in different industries including the aviation industry for many years due to their high weight-to-strength ratio, high rigidity, design flexibility, and other benefits. The structure and size of glass fibers vary greatly (Mazloom and Mirzamohammadi 2019). The smallest of them are not visible to the naked eye. Glass fibers become the most common fibers that are employed in composites (Mirjavadi *et al.* 2020). Glass fibers are delicate and flexible fibers that are made of glass. Glass fibers with a fixed diameter of about 5 to 25 microns and unlimited length are produced (Bakir *et al.* 2017). They are popular as thermal insulation and usually have many disadvantages on their surface due to wear between the fibers. Moisture has detrimental effects on the strength of glass fibers. They are used in many industries, including aerospace, due to their excellent elasticity, low density, shock resistance, low cost, and electrical insulation (Yang *et al.* 2019). Binder can be used to hold the fibers together. Binder selection is based on the application of materials. The durability of a composite piece is affected by the binder type (Rahman *et al.* 2017).

### 2.2 Basalt fibers

With the increasing use of synthetic fibers, more

industries are becoming interested in basalt fibers. Basalt is a natural and neutral volcanic rock with a wide range of access around the world. The first attempts to produce basalt fibers from its melt were made in 1923 in the United States. During World War II, and in the 1950s, research in some countries improved the knowledge and technology of basalt fiber production, but no commercial product was produced. Basalt is a type of hard and black volcanic rock formed by the solidification of magma from the subsoil of the Earth's crust at the surface or on the seabed. Basalt has 45 to 52 percent silica oxide, 12 to 16 percent aluminum oxide, 6 to 18 percent iron oxide, 10 to 20 percent alkaline earth metals, and 2 to 8 percent other alkali metals. The existing technology for the production of basalt fibers is very similar to the technology that is used in the production of E-Glass fibers. The main difference in technology is that they are made from a complex mixture of materials, while basalt fibers are made from basalt melt without any additives. Basaltic materials do not cause any environmental problems and are not dangerous. Basalt fibers have a unique combination with high technical properties, including resistance to corrosion and heat. These features, in addition to the low price of basalt fibers, making it possible for basalt fibers to compete with glass fibers such as S-type glass fibers. The mechanical properties of basalt play an essential role in this reinforcement in the aviation and aerospace industries (Altabay 2017, Saleem *et al.* 2020, Wang *et al.* 2020).

### 2.3 Aramid fibers

Aramid is a general term for circular polyamides. In general, aramids have higher chemical resistance, better thermal stability, glass transfer temperature, and higher melting point than aliphatic polyamides. Aramid polymers are known for their high melting point, excellent thermal stability, flame resistance, and insolubility in many organic and inorganic solvents. The sum of aromatic polymers has a density between 1.43 and 1.46 g/cm<sup>3</sup>, while other types have lower densities of about 1.2 to 1.4 g/cm<sup>3</sup>. Aramid fibers are now known in the industry as the Kevlar brand. The tensile strength of Kevlar fibers is approximately 55% of the tensile strength of glass fibers, and its shear strength is 180% of glass fibers. The tensile strength of Kevlar fibers is also 10% less than that of carbon fiber. UV light destroys aramid fibers. The extent of this degradation depends on the thickness of the Kevlar fiber, as the Kevlar fibers play a protective role, and the destruction of the top layers prevents the destruction of the underlying layers. This problem is less important in composite structures. Because the composite matrix or resin plays a role in protecting the fibers to some extent (Gu *et al.* 2020, Jia *et al.* 2020).

### 2.4 Nanofillers utilized in aviation and areospace applications

#### 2.4.1 Carbon nanotubes (CNTs)

CNTs are one of the most useful components in materials science. These components can be manufactured in a variety of ways, and one of the new applications that have been discovered for them is the use of these nanotubes

as stitching connections, which can be useful in the aerospace industry (Farazin and Mohammadimehr 2020). CNTs are also a breakthrough in nanotechnology. These materials are very light, CNTs have many capabilities, including high energy storage and resistance to various radiation. CNTs are very small particles like invisible filaments (Unnikrishnan *et al.* 2011). Millions of pieces of these invisible strings combine to form useful, and visible material. These nanoparticles are many useful mechanical and electrical properties that are widely used in the aerospace industry. For example, it is possible to build a light and strong spacecraft that is resistant to space radiation with such materials (Aydogdu 2014). Spacecraft are usually destroyed when they enter the atmosphere due to exposure to very high temperatures and cannot be reused. Thermal resistance to high temperatures when returning to the atmosphere is a demand that CNTs can withstand due to their high thermal conductivity (Civalek *et al.* 2020).

Today's advanced aircraft of the world's largest companies, such as Boeing and Airbus, are made of modern composite materials. These materials, which are reinforced plastics with carbon fibers, drastically reduce the weight of the aircraft and reduce fuel consumption. The weight of aircraft made of composite materials is 20 percent less than those made of aluminum alloys. CNTs are about the thickness of a carbon molecule and, despite their microscopic structure, they are highly resistant (Kim *et al.* 2009). To make the new material, the scientists inserted nanocarbon fibers into a polymeric field with adhesive properties and then pressed the mixture between layers of carbon fiber composite. The CNTs act as vertical stitches in this material, bonding the composite layers together. The composite made showed 30% more resistance than conventional composites in experiments (Bellucci *et al.* 2007). Composites made of carbon nanotubes can be used to make aircraft parts, especially those that require bolts and nuts (Hajmohammad *et al.* 2018). Of course, research is still in its infancy, but the results could lead to lighter aircraft with lower fuel consumption (Hussain *et al.* 2019, 2020).

#### 2.4.2 Graphene platlets (GPLs)

GPL is a two-dimensional structure with a hexagonal network of carbon atoms arranged side by side with a covalent bond. GPL has different types of one, two, and several layers, each of which has its properties as well as unique applications; also, graphene is one of the other forms of carbon. The unusual attributes of GPL include a large surface area (2630 m<sup>2</sup>/g), an extraordinary Young's modulus (1 TPa), exceptional conductivity (Bouadi *et al.* 2018, Ebrahimi *et al.* 2019).

### 2.5 Experimental method

Polymers for making nanocomposites can be made chemically or mechanically (Ahuja and Kumar 2009). For the fabrication of polymer nanocomposites, uniform distribution of nanofillers (reinforcements) in polymeric materials (matrices) is necessary. The size of the reinforcements is at micro and nano scales, which must disperse nanoparticles into the polymer (matrix) to strengthen the composites. In this regard, some researchers have made great efforts to use the chemical reaction of complex polymerization or surface modification of fillers to make uniform distribution of nanofillers (reinforcements) in polymeric materials (matrices) (Koutu *et al.* 2019). Composites are usually made by the following methods:

#### 2.5.1 Sol-Gel method

The sol-gel method is a wet chemical method and widely used in materials engineering to synthesize a variety of nanostructures. By using the sol-gel method, high quality and high purity nanoparticles can be prepared. This approach is shown in Fig. 1. The sol-gel method is a common and industrial method for synthesizing nanoparticles with different chemical compositions. The basis of the sol-gel method is the production of a homogeneous sol of precursors and its conversion into a gel. Then the solvent in the gel is removed from the gel structure and the remaining gel is dried. The properties of

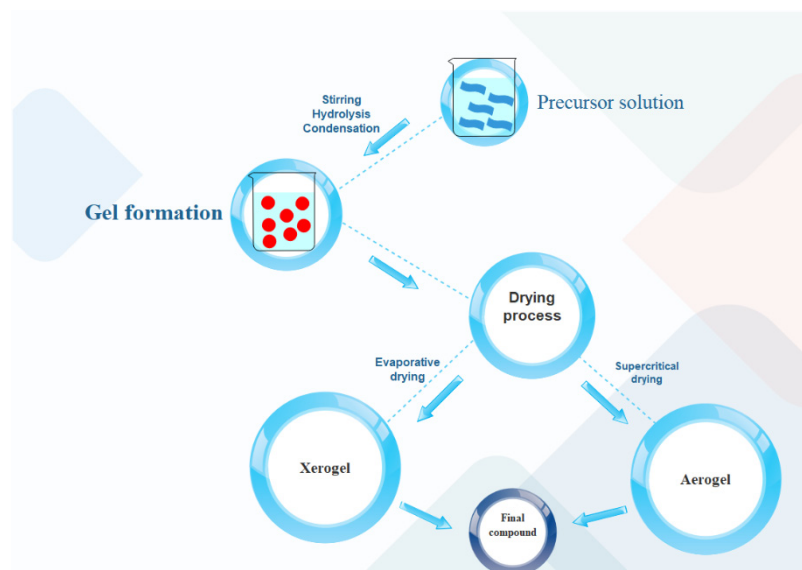


Fig. 1 Schematic of the sol-gel fabrication process

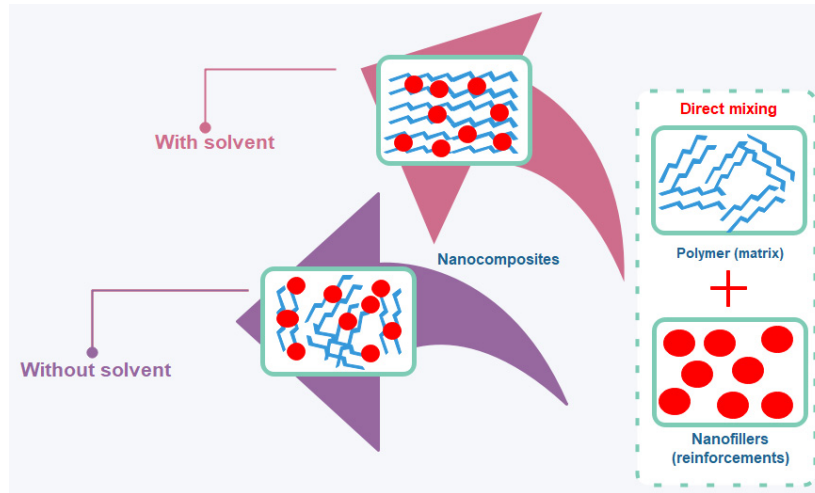


Fig. 2 Two methods for fabrication composites with polymer as matrix and nanofillers as reinforcements

the dried gel depend significantly on its drying method. Dried gels are used in a variety of ways in industries including aircraft surface coating. It is worth noting that by grinding the gel with special mills, it is possible to achieve nanoscale particles. In the sol-gel approach, the conversion of sol to gel is usually done by varying pH. The main advantages of the sol-gel approach are the high purity of the product, the narrow distribution of particle size, and the achievement of uniform nanostructures at low temperatures. This method is commonly used to synthesize metal nanoparticles (Wang and Bierwagen 2009, Wen and Wilkes 1996).

### 2.5.2 Direct mixing polymer and nanofillers as reinforcements

As shown in Fig. 2, direct mixing of nanofillers (reinforcements) and polymers (matrices) is a top-down approach to fabricating nanocomposites. It is shown from Fig. 2 that direct mixing of nanofillers (reinforcements) and polymers (matrices) is a top-down approach to fabricating nanocomposites. This method is based on the placement of dissolved or mixed nanoparticles during the mixing process in which is proper for fabricating polymeric nanocomposites is two general methods for combining nanofillers and polymers, and these two methods are always fixed for all industries (Wu *et al.* 2020). In the absence of any solvents, the mixing of one-way polymer with nanofillers over the glass transition temperature ( $T_g$ ) of the polymer, commonly named the melt compounding method. The other method involves mixing nanofillers in a solution using solvents, commonly referred to as solvent mixing methods/solutions (McKechnie *et al.* 2020).

## 2.6 Development of structural composite materials

### 2.6.1 Large commercial transport aircraft

Different types of composites have different mechanical properties, which is why each part of the aircraft is produced with a specific type of composite. In the 1960s, the aircraft's aluminum wings were somewhat resistant to fatigue, but this was not the case with carbon fiber.

However, the manufacturers of these fibers have constantly improved their mechanical properties, and today the resistance of these fibers to fatigue and shock has greatly increased. Boron fibers are also very resistant to fatigue, which is why the fibers were used on the wings of tactical warplanes. The first composite in aircraft was designed and built as part of NASA's program. NASA's main goal was to gain real-world flight experience with composite structures. Three airlines are used Narmco T300 / 5208 graphite/epoxy material system. In the early years of composite materials, small structures were designed with barbecues and used by aircraft manufacturers. In later years, larger, heavier surfaces, stronger and more durable structures, and aircraft design companies are used. There are some samples of these composite structures used by aircraft manufacturers and used in the Boeing B-727

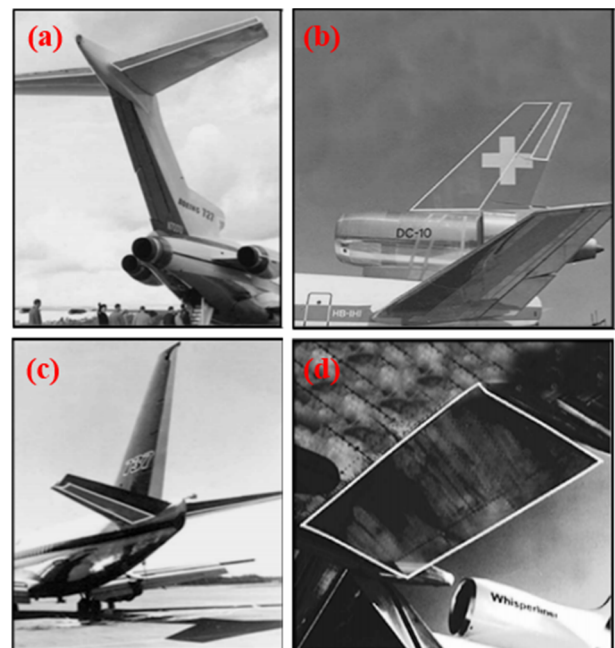


Fig. 3 Typical industrial applications done by the NASA's program

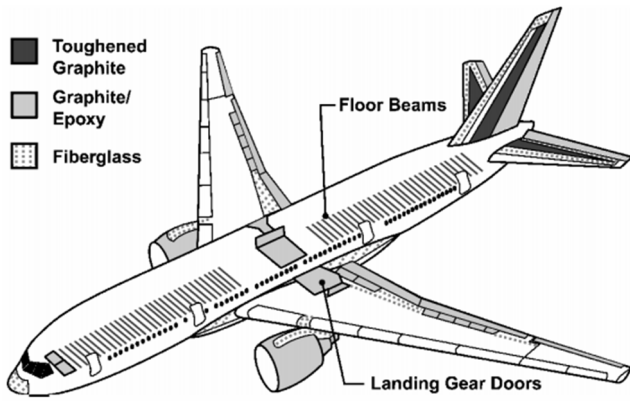


Fig. 4 Schematic of composite structures that used in Boeing B-777

elevator (Fig. 3(a)), the Douglas DC-10 vertical stabilizer (Fig. 3(b)), the Boeing B-737 horizontal stabilizer (Fig. 3(c)), and the Lockheed L-1011 aileron (Fig. 3(d)) (Harris *et al.* 2002). Another significant airplane is Boeing 787-Dreamliner in terms of composite usage and fuel-efficiency. The industry-leading technology of the 787 Dreamliner is creating remarkable opportunities for airlines around the world and dramatically improving the air travel experience. The airplane’s unparalleled fuel efficiency and range flexibility enables carriers to profitably open new routes as well as optimize fleet and network performance. And for their passengers, an experience like none other in the air, with more comfort and less fatigue (Pandian *et al.* 2020).

All three main flight components had significant problems before redesigning and successfully testing. As of January 1987, 350 composite parts had entered the commercial airline’s flight service and were used by aircraft manufacturers. As of 1993, 350 composite structures are located in service that had accumulated over 5.3 million flight hours. The performance of composite parts, maintenance characteristics, and residual resistance after the flight was reported to NASA and compared with data obtained before the flight. The data obtained from the composite materials show the excellent performance of the composite materials for 15 years. But after a while, the airlines reported damages such as accidents when hitting

the ground, damage from collisions with foreign objects, and lightning strikes. However, there are no reports of composite damage due to fatigue or exposure to the environment during flight. Also, there is a high-quality correlation between the laboratory results and the structural performance of the actual aircraft parts. The Boeing B-777 makes the wide application of composite material for principal structure in the empennage. These significant composite parts are illustrated schematically in Fig. 4 (Harris *et al.* 2002). As the schematic shows, several parts of the mentioned aircraft are made of different composite materials. Graphite-epoxy composite are utilized for most secondary structure and control surfaces. A composite structure made of rigid epoxy material (Toray T800H / 3900-2) is utilized for larger and more pressurized parts. In a test program, Boeing replaced 11,000 metal parts of a helicopter with 1,500 composite components. With this measure, the maintenance period of the mentioned parts is increased, and it was not long before the same replacement took place in commercial and recreational planes. In the aerospace industry, carbon fiber is used more than any other fiber (Ott *et al.* 2019).

### 2.6.2 Applications of sandwich composite structures in the aerospace industries

Sandwich composites consist of a core that is weak, bulky, and strong face sheets on either side of the core. The core is made of foam or honeycomb, and the face sheets on either side of the core are made of glass fiber or natural fiber composites (Gladkovsky *et al.* 2019). These sandwich panels have a much higher resistance than any of their components, these panels are also lightweight and low cost. Advantages of sandwich panels: Due to the use of lightweight materials in the core, the weight of the panel is greatly reduced. Despite its lightweight, it is extremely resistant to all types of compressive and impact loads. These composite structures absorb the force exerted on them, making them more durable (Balázs *et al.* 2020). These panels do not corrode due to humidity and environmental conditions, and as a result, their maintenance costs are reduced and their lifespan is longer. Also, these sandwich panels have high strength. For this reason, the tendency to use these structures in the fuselage and wing of

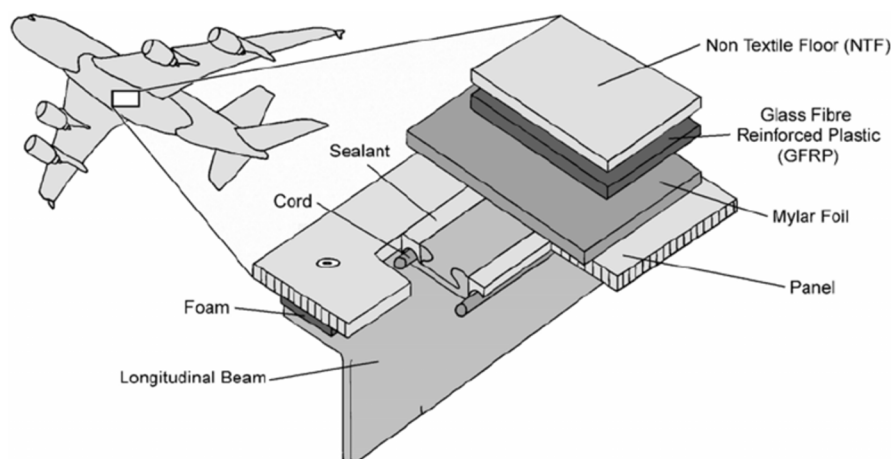


Fig. 5 Advanced composite structures utilized in aviation industry

Table 1 Attributes of some fibers used in the aerospace and aviation industries as reinforcements

Types of fibers	Classifications of reinforcements
Para-Aramid	Twaron, Teijin has a tensile strength approximately equal to of 3100 MPa Kevlar 29, DuPont has a tensile strength approximately equal to 2965 MPa
Ceramic fibers	Alumina (Nextel, 3 M) has tensile strength approximately equal to 1720 MPa Silicon Carbide has tensile strength approximately equal to 4000 MPa
Carbon fiber	Standard tensile strength is approximately equal to 3651 MPa Celion has tensile strength approximately equal to 4000 MPa Aksaca has tensile strength approximately equal to 4200 MPa
Glass fibers	S-Glass has tensile strength approximately equal to 4400 MPa E-Glass has tensile strength approximately equal to 3500 MPa
Atomistic polyester	M5 has tensile strength approximately equal to 3960 MPa

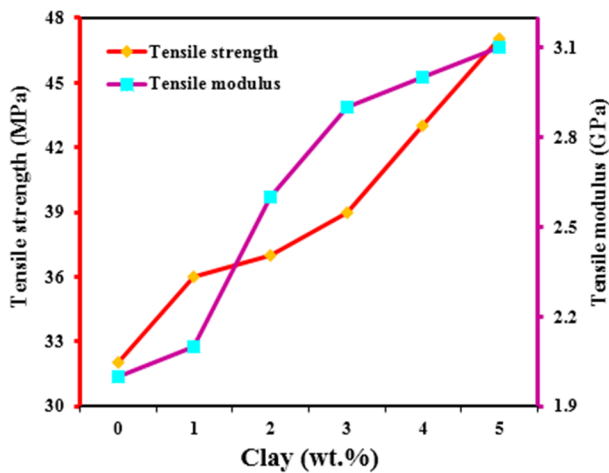


Fig. 6 Variety and changes of tensile strength and tensile modulus with clay content in nylon-6 nanocomposite

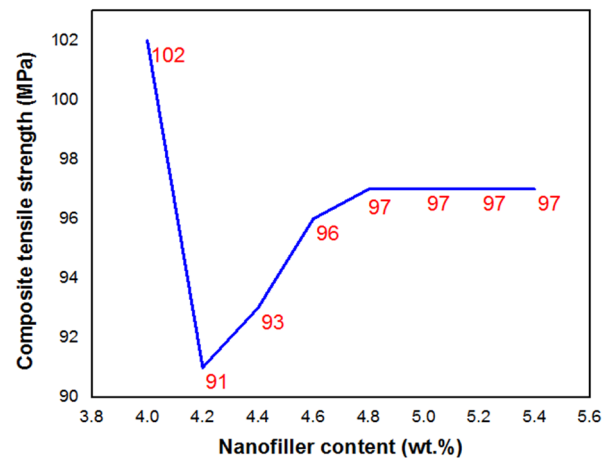


Fig. 7 Variety of tensile strength of composite with nanofiller content in nylon-6 exfoliated

the aircraft has increased significantly. In many honeycomb composites, such as those used in aircraft wings and fuselage, a plastic shaped honeycomb may be reinforced between two composite shells or carbon fibers (Li and Wang 2017). The wing, tail, propeller, and rotating parts of the aircraft are mainly of advanced composites as shown in Fig. 5 (Masselter and Speck 2011). Aircraft are less likely to have a complete failure of composites than metals such as aluminum under stress. A small crack inside a piece of metal can spread quickly and have devastating results, but in fiber composites such as a dam, they resist cracking and spread the stress to the environment. Reinforced composites are resistant to heat and corrosion (Letti *et al.* 2017).

### 3. Results and discussion

There are many studies about fibers that are used in the aviation and aerospace industries. (Fu *et al.* 2014) stated that some fibers can be used as reinforcements in aerospace and aviation structures because of their high strength and good mechanical and physical properties. In Table 1 (Alubel *et al.* 2019), the properties of some fibers used in the aerospace and aviation industries are shown. Para amide fiber has a better heat resistance and tensile strength than

amide groups due to its intense adhesion between amide and aromatic groups (Bilisik 2017).

Fu *et al.* (1999) described in their study that with enhancing of the aspect ratio of reinforcements, the strength and modulus of composite enhance commonly. Fig. 6 presents increasing the particle content leads to enhance the tensile strength and Young's modulus of nylon with clay and moreover, similar results are obtained for polyurethane/clay nanocomposites.

Sheng *et al.* (2004) reported that adding only a few percent of clay increases the resistance of nanocomposites composed of nylon-6 as shown in Fig. 7.

They also reported that Intercalated nanocomposites were less resistant. By reducing the size of  $\text{CaCO}_3$  particles, the composite strength enhances. (Alexandre *et al.* 2001) stated that the tensile strength of composites increases with increasing of reinforcement at certain values in polystyrene, then with increasing the amount of nanofiller, as shown in Fig. 8, the strength of this value decreases.

Jisheng *et al.* (2001) demonstrated the mechanical and physical properties of polymeric nanocomposites (intercalated or exfoliated). Strength increases by adding clay nanoparticles to intercalated/exfoliated nanocomposites. Table 2 shows this effect, in which the tensile strength of polyurethane (PU) polyester elastomeric clay nanocomposite connected increases. With an increase in the

Table 2 Variety of tensile strength with clay content in PU nanocomposites

Specimen number	Clay contain (wt %)	Tensile strength (MPa)	Elongation at break (%)
1	0	0.66	75.50
2	2.8	1.01	100.01
3	5.1	1.23	176
4	8.3	1.44	333
5	10.2	1.32	226

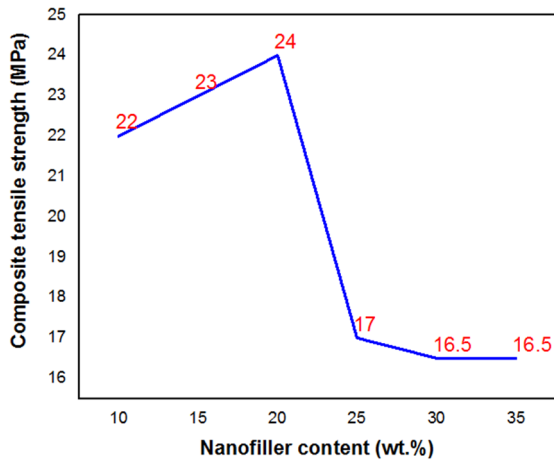


Fig. 8 Variety of tensile strength of composite with nanofiller content in polystyrene

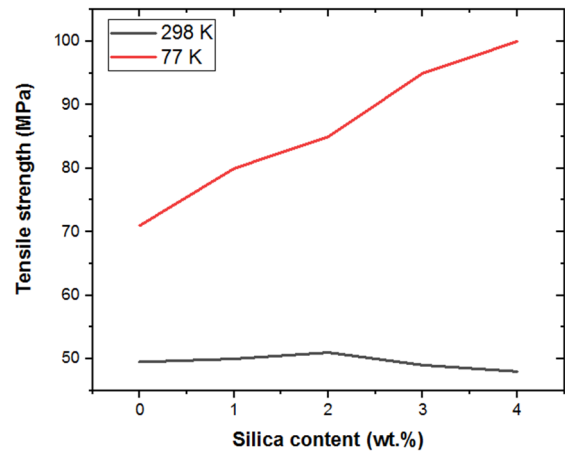


Fig. 9 Tensile strength of silica/epoxy at different temperatures

amount of clay (from 0 to 8 wt%), the tensile strength also increases, and reaches a maximum of 8 wt%.

The main reason for this significant difference in the thermal expansion between the silica nanoparticles and the epoxy resin at ambient temperature. (Salvetat *et al.* 1999) stated in their article that nanoscale reinforcements such as CNTs have very high physical and mechanical properties. Table 3 displays direct relation among stress and strain at 77 K for composites reinforced with carbon nanotubes, and thus these specimens display brittle behaviors. (Ou *et al.*

Table 3 The relation among stress and strain on CNTs content at 77 K

Type of CNT	CNTs (wt. %)	Stress (MPa)	Strain (%)
SWCNT	0.22	21	0.51
		42	1.01
		62	1.53
	0.51	25	0.54
		44	1.01
		73	1.55
MWCNT	1.1	31	0.52
		72	1.01
		91	1.52
		0	84.8
MWCNT	0.25	120.38	-
	0.51	134.29	-

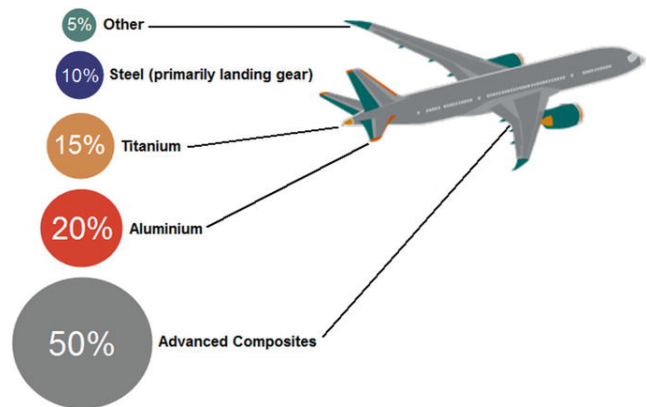


Fig. 10 General schematic of the division of aircrafts structure

Table 4 Modified and unmodified SiO<sub>2</sub> particles used in the aviation and aerospace industries with tensile strength of nanocomposites based on nylon-6 filled

Types of silica (SiO <sub>2</sub> )	SiO <sub>2</sub> content	Stress (MPa)	Modulus (GPa)	Elongation at break (%)
Modified	0	76.05	2.06	109
	5	84.01	2.37	251.
	10	78.02	2.51	152
	15	76.5	2.61	111
	0	76.01	2.02	107
Unmodified	5	75.05	2.24	106
	10	73.5	2.44	91

1998) stated in their paper that the maximum stress value for modified silica is 5wt% then stress decreases after 5wt%. Table 4 shows that when the content of unmodified silica increases with weight percentage, the stress decreases or stabilizes.

Finally, in the current century, as shown in Fig. 10, about half of the aircraft structure is made of advanced composites (Di Sante 2015), and the role of advanced composites in the aerospace and aviation industries is expected to increase significantly in the coming years. Therefore, the knowledge of making advanced, light, and strong composites can be an important help for these industries.

#### 4. Conclusions

In this comprehensive study mechanical behavior, physical and mechanical properties of polymeric composites, various types of reinforcements, different methods to fabricate polymeric composites, historical structural composite materials for aviation, and aerospace industries and different methods for their characterization were reported. The most important results are as follows:

- (1) CNTs are capable of withstanding very high temperatures, and also CNTs have many mechanical and electrical properties that are widely used in the aerospace industry.
- (2) Improving the mechanical and physical properties of composites depends on the type of reinforcements, their size, and their weight percentage.
- (3) Properties of composites also depend on the method used in the manufacture of them.
- (4) The intercalation process for the fabrication of composites is the top-down procedure.
- (5) The sol-gel method is very common for fabricating polymer composites. This method is used for 1D fillers such as CNTs.
- (6) The use of composite structures in the aerospace and aviation industries from 2005 to 2020 has grown more than 400%.

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#### References

- AkhavanAlavi, S.M., Mohammadimehr, M. and Edjtahed, S.H. (2019), "Active control of micro Reddy beam integrated with functionally graded nanocomposite sensor and actuator based on linear quadratic regulator method", *Eur. J. Mech.-A/Solids*, **74**, 449-461. <https://doi.org/10.1016/j.euromechsol.2018.12.008>
- Ahmed, S., Chakrabarty, D., Mukherjee, S., Joseph, A., Jhala, G. and Bhowmik, S. (2014), "Investigation on nanoadhesive bonding of plasma modified titanium for aerospace application", *Adv. Aircr. Spacecr. Sci.*, **1**(1), 1-14. <https://doi.org/10.12989/aas.2014.1.1.001>
- Alexandre, M., Beyer, G., Henrist, C., Cloots, R., Rulmont, A., Jérôme, R. and Dubois, P. (2001), "One-Pot" Preparation of Polymer/Clay Nanocomposites Starting from Na<sup>+</sup> Montmorillonite. 1. Melt Intercalation of Ethylene-Vinyl Acetate Copolymer", *Chem. Mater.*, **13**(11), 3830-3832. <https://doi.org/10.1021/cm011095m>
- Altabay, W.A. (2017), "An exact solution for mechanical behavior of BFRP Nano-thin films embedded in NEMS", *Adv. Nano Res., Int. J.*, **5**(4), 337-358. <https://doi.org/10.12989/anr.2017.5.4.337>
- Alubel, M., Boussu, F., Bruniaux, P., Loghin, C. and Cristian, I. (2019), "Ballistic impact mechanisms – A review on textiles and fibre-reinforced composites impact responses", *Compos. Struct.*, **223**, 110966. <https://doi.org/10.1016/j.compstruct.2019.110966>
- Anvari, M., Mohammadimehr, M. and Amiri, A. (2020), "Vibration behavior of a micro cylindrical sandwich panel reinforced by graphene platelet", *J. Vib. Control*, 107754631989273. <https://doi.org/10.1177/1077546319892730>
- Arani, A.G., Kiani, F. and Afshari, H. (2019), "Aeroelastic analysis of laminated FG-CNTRC cylindrical panels under yawed supersonic flow", *Int. J. Appl. Mech.*, **11**(6), 1950052. <https://doi.org/10.1142/S1758825119500522>
- Arefi, M., Mohammad-Rezaei Bidgoli, E., Dimitri, R. and Tornabene, F. (2018), "Free vibrations of functionally graded polymer composite nanoplates reinforced with graphene nanoplatelets", *Aerosp. Sci. Technol.*, **81**, 108-117. <https://doi.org/10.1016/j.ast.2018.07.036>
- Arshid, E., Amir, S. and Loghman, A. (2020), "Static and dynamic analyses of FG-GNPs reinforced porous nanocomposite annular micro-plates based on MSGT", *Int. J. Mech. Sci.*, **180**, 105656. <https://doi.org/10.1016/j.ijmecsci.2020.105656>
- Aydogdu, M. (2014), "On the vibration of aligned carbon nanotube reinforced composite beams", *Adv. Nano Res., Int. J.*, **2**(4), 199-210. <http://dx.doi.org/10.12989/anr.2014.2.4.199>
- Babaeian, M. and Mohammadimehr, M. (2020), "Investigation of the time elapsed effect on residual stress measurement in a composite plate by DIC method", *Optics Lasers Eng.*, **128**, 106002. <https://doi.org/10.1016/j.optlaseng.2020.106002>
- Bakir, N., Abbeche, K. and Panczer, G. (2017), "Experimental study of the effect of the glass fibers on reducing collapse of a collapsible soil", *Geomech. Eng., Int. J.*, **12**(1), 71-83. <https://doi.org/10.12989/gae.2017.12.1.071>
- Balázi, K., Furkó, M., Liao, Z., Fogarassy, Z., Medved, D., Zschech, E., Dusza, J. and Balázi, C. (2020), "Graphene added multilayer ceramic sandwich (GMCS) composites: Structure, preparation and properties", *J. Eur. Ceram. Soc.*, **40**(14), 4792-4798. <https://doi.org/10.1016/j.jeurceramsoc.2020.01.054>
- Bellucci, S., Balasubramanian, C., Micciulla, F. and Rinaldi, G. (2007), "CNT composites for aerospace applications", *J. Experim. Nanosci.*, **2**(3), 193-206. <https://doi.org/10.1080/17458080701376348>
- Bilisik, K. (2017), "Two-dimensional (2D) fabrics and three-dimensional (3D) preforms for ballistic and stabbing protection: A review", *Textile Res. J.*, **87**(18), 2275-2304. <https://doi.org/10.1177/0040517516669075>
- Bouadi, A., Bousahla, A.A., Houari, M.S.A., Heireche, H. and Tounsi, A. (2018), "A new nonlocal HSDT for analysis of stability of single layer graphene sheet", *Adv. Nano Res., Int. J.*, **6**(2), 147-162. <https://doi.org/10.12989/anr.2018.6.2.147>
- Civalek, Ö., Dastjerdi, S. and Akgöz, B. (2020), "Buckling and free vibrations of CNT-reinforced cross-ply laminated composite plates", *Mech. Based Des. Struct. Mach.*, 1-18. <https://doi.org/10.1080/15397734.2020.1766494>
- Di Sante, R. (2015), "Fibre Optic Sensors for Structural Health Monitoring of Aircraft Composite Structures: Recent Advances

- and Applications”, *Sensors*, **15**(8), 18666-18713.  
<https://doi.org/10.3390/s150818666>
- Ebrahimi, F., Nouraei, M., Dabbagh, A. and Rabczuk, T. (2019), “Thermal buckling analysis of embedded graphene-oxide powder-reinforced nanocomposite plates”, *Adv. Nano Res., Int. J.*, **7**(5), 293-310. <https://doi.org/10.12989/anr.2019.7.5.293>
- Farazin, A. and Mohammadimehr, M. (2020), “Nano research for investigating the effect of SWCNTs dimensions on the properties of the simulated nanocomposites: a molecular dynamics simulation”, *Adv. Nano Res., Int. J.*, **9**(2), 83-90.  
<https://doi.org/10.12989/anr.2020.9.2.083>
- Farazin, A., Aghdam, H.A., Motififard, M., Aghadavoudi, F., Kordjamshidi, A., Saber-Samandari, S., Esmaceli, S. and Khandan, A. (2019), “A polycaprolactone bio-nanocomposite bone substitute fabricated for femoral fracture approaches: Molecular dynamic and micro-mechanical Investigation”, *J. Nanoanal.*, **6**(3), 172-184.  
<https://doi.org/10.22034/JNA.2019.668028>
- Farazin, A., Aghadavoudi, F., Motififard, M., Saber-Samandari, S. and Khandan, A. (2020), “Nanostructure, molecular dynamics simulation and mechanical performance of PCL membranes reinforced with antibacterial nanoparticles”, *J. Appl. Computat. Mech.* <https://doi.org/10.22055/JACM.2020.32902.2097>
- Fu, S.-Y., Hu, X. and Yue, C.-Y. (1999), “The flexural modulus of misaligned short-fiber-reinforced polymers”, *Compos. Sci. Technol.*, **59**(10), 1533-1542.  
[https://doi.org/10.1016/S0266-3538\(99\)00022-6](https://doi.org/10.1016/S0266-3538(99)00022-6)
- Fu, L., Tang, K., Song, K., Van Aken, P.A., Yu, Y. and Maier, J. (2014), “Nitrogen doped porous carbon fibres as anode materials for sodium ion batteries with excellent rate performance”, *Nanoscale*, **6**(3), 1384-1389.  
<https://doi.org/10.1039/c3nr05374a>
- Fu, S., Sun, Z., Huang, P., Li, Y. and Hu, N. (2019), “Some basic aspects of polymer nanocomposites: A critical review”, *Nano Mater. Sci.*, **1**(1), 2-30.  
<https://doi.org/10.1016/j.nanoms.2019.02.006>
- Ghasemi, A.R., Mohandes, M., Dimitri, R. and Tornabene, F. (2019), “Agglomeration effects on the vibrations of CNTs/fiber/polymer/metal hybrid laminates cylindrical shell”, *Compos. Part B: Eng.*, **167**, 700-716.  
<https://doi.org/10.1016/j.compositesb.2019.03.028>
- Ghorbanpour Arani, A. and Soleymani, T. (2019), “Size-dependent vibration analysis of an axially moving sandwich beam with MR core and axially FGM faces layers in yawed supersonic airflow”, *Eur. J. Mech. - A/Solids*, **77**, 103792.  
<https://doi.org/10.1016/j.euromechsol.2019.05.007>
- Ghorbanpour Arani, A., Roustavi Navi, B. and Mohammadimehr, M. (2016), “Surface stress and agglomeration effects on nonlocal biaxial buckling polymeric nanocomposite plate reinforced by CNT using various approaches”, *Adv. Compos. Mater.*, **25**(5), 423-441. <https://doi.org/10.1080/09243046.2015.1052189>
- Ghorbanpour Arani, A., BabaAkbar Zarei, H. and Haghparsat, E. (2018), “Vibration response of viscoelastic sandwich plate with magnetorheological fluid core and functionally graded-piezoelectric nanocomposite face sheets”, *J. Vib. Control*, **107754631774750**. <https://doi.org/10.1177/1077546317747501>
- Gladkovsky, S.V., Kuteneva, S.V. and Sergeev, S.N. (2019), “Materials Characterization Microstructure and mechanical properties of sandwich copper / steel composites produced by explosive welding”, *Mater. Characteriz.*, **154**, 294-303.  
<https://doi.org/10.1016/j.matchar.2019.06.008>
- Gu, W., Liu, X., Ye, Q., Gao, Q., Gong, S., Li, J. and Shi, S.Q. (2020), “Bio-inspired co-deposition strategy of aramid fibers to improve performance of soy protein isolate-based adhesive”, *Indust. Crops Products*, **150**, 112424.  
<https://doi.org/10.1016/j.indcrop.2020.112424>
- Hajmohammad, M.H., Zarei, M.S., Farrokhan, A. and Kolahchi, R. (2018), “A layerwise theory for buckling analysis of truncated conical shells reinforced by CNTs and carbon fibers integrated with piezoelectric layers in hygrothermal environment”, *Adv. Nano Res., Int. J.*, **6**(4), 299-321.  
<http://dx.doi.org/10.12989/anr.2018.6.4.299>
- Harris, C.E., Starnes, J.H. and Shuart, M.J. (2002), “Design and Manufacturing of Aerospace Composite Structures, State-of-the-Art Assessment”, *J. Aircr.*, **39**(4), 545-560.  
<https://doi.org/10.2514/2.2992>
- Hejri, Z., Hejri, M., Omidvar, M. and Morshedi, S. (2020), “A novel nanocomposite as adsorbent for formaldehyde removal from aqueous solution”, *Adv. Nano Res., Int. J.*, **8**(1), 1-11.  
<https://doi.org/10.12989/anr.2020.8.1.001>
- Huang, C.J., Fu, S.Y., Zhang, Y.H., Lauke, B., Li, L.F. and Ye, L. (2005), “Cryogenic properties of SiO<sub>2</sub>/epoxy nanocomposites”, *Cryogenics*, **45**(6), 450-454.  
<https://doi.org/10.1016/j.cryogenics.2005.03.003>
- Hussain, M., Naeem, M.N., Tounsi, A. and Taj, M. (2019), “Nonlocal effect on the vibration of armchair and zigzag SWCNTs with bending rigidity”, *Adv. Nano Res., Int. J.*, **7**(6), 431-442. <https://doi.org/10.12989/anr.2019.7.6.431>
- Hussain, M., Naeem, M.N., Taj, M. and Tounsi, A. (2020), “Simulating vibration of single-walled carbon nanotube using Rayleigh-Ritz’s method”, *Adv. Nano Res., Int. J.*, **8**(3), 215-228.  
<https://doi.org/10.12989/anr.2020.8.3.215>
- Jia, C., Zhang, R., Yuan, C., Ma, Z., Du, Y., Liu, L. and Huang, Y. (2020), “Surface modification of aramid fibers by amino functionalized silane grafting to improve interfacial property of aramid fibers reinforced composite”, *Polym. Compos.*, **41**(5), 2046-2053. <https://doi.org/10.1002/pc.25519>
- Jisheng, M.A., Zongneng, Q.I. and Shufan, Z. (2001), “Synthesis and characterization of elastomeric polyurethane/clay nanocomposites”, *Acta Polymerica Sinica*, **82**(6), 1444-1448.  
<https://doi.org/10.1002/app.1982>
- Khandan, A., Saber-Samandari, S., Telloo, M., Kazeroni, Z.S., Esmaceli, S., Sheikhabaei, E. and Kamyab, B. (2020), “A Mitral Heart Valve Prototype Using Sustainable Polyurethane Polymer: Fabricated by 3D Bioprinter, Tested by Molecular Dynamics Simulation”, *AUT J. Mech. Eng.*  
<https://doi.org/10.22060/AJME.2020.17450.5862>
- Khater, H.M. (2016), “Nano-Silica effect on the physicomechanical properties of geopolymer composites”, *Adv. Nano Res., Int. J.*, **4**(3), 181-195.  
<https://doi.org/10.12989/anr.2016.4.3.181>
- Kim, J.-W., Galanzha, E.I., Shashkov, E.V., Moon, H.-M. and Zharov, V.P. (2009), “Golden carbon nanotubes as multimodal photoacoustic and photothermal high-contrast molecular agents”, *Nature Nanotechnol.*, **4**(10), 688-694.  
<https://doi.org/10.1038/nnano.2009.231>
- Koutu, V., Rajawat, S., Shastri, L. and Malik, M.M. (2019), “Apoptosis and inhibition of human epithelial cancer cells by ZnO nanoparticles synthesized using plant extract”, *Adv. Nano Res., Int. J.*, **7**(4), 233-240.  
<https://doi.org/10.12989/anr.2019.7.4.233>
- Letti, C.J., Costa, K.A.G., Gross, M.A., Paterno, L.G., Pereira-da-Silva, M.A., Morais, P.C. and Soler, M.A.G. (2017), “Synthesis, morphology and electrochemical applications of iron oxide based nanocomposites”, *Adv. Nano Res., Int. J.*, **5**(3), 215-230.  
<https://doi.org/10.12989/anr.2017.5.3.215>
- Li, T. and Wang, L. (2017), “Bending behavior of sandwich composite structures with tunable 3D-printed core materials”, *Compos. Struct.*, **175**, 46-57.  
<https://doi.org/10.1016/j.compstruct.2017.05.001>
- Masalov, V.M., Dolganov, P.V., Sukhinina, N.S., Dolganov, V.K. and Emelchenko, G.A. (2014), “Synthesis of polymer-based inverted opal and transformation of its optical properties”, *Adv. Nano Res., Int. J.*, **2**(1), 69-76.

- <https://doi.org/10.12989/anr.2014.2.1.069>
- Masselter, T. and Speck, T. (2011), *Biomimetic fiber-reinforced compound materials*, Intech.
- Mazloom, M. and Mirzamohammadi, S. (2019), "Thermal effects on the mechanical properties of cement mortars reinforced with aramid, glass, basalt and polypropylene fibers", *Adv. Mater. Res., Int. J.*, **8**(2), 137-154.  
<https://doi.org/10.12989/anr.2019.8.2.137>
- Mckechnie, D., Cree, J., Wadkin-snaith, D. and Johnston, K. (2020), "Glass transition temperature of a polymer thin film: Statistical and fitting uncertainties", *Polymer*, **195**, 122433.  
<https://doi.org/10.1016/j.polymer.2020.122433>
- Mehar, K. and Panda, S.K. (2019), "Multiscale modeling approach for thermal buckling analysis of nanocomposite curved structure", *Adv. Nano Res., Int. J.*, **7**(3), 181-190.  
<https://doi.org/10.12989/anr.2019.7.3.181>
- Mirjavadi, S.S., Forsat, M., Barati, M.R. and Hamouda, A.M.S. (2020), "Nonlinear forced vibrations of multi-scale epoxy/CNT/ fiberglass truncated conical shells and annular plates via 3D Mori-Tanaka scheme", *Steel Compos. Struct., Int. J.*, **35**(6), 765-777.  
<https://doi.org/10.12989/scs.2020.35.6.765>
- Mohammadimehr, M., Roustavi Navi, B. and Ghorbanpour Arani, A. (2015), "Free vibration of viscoelastic double-bonded polymeric nanocomposite plates reinforced by FG-SWCNTs using MSGT, sinusoidal shear deformation theory and meshless method", *Compos. Struct.*, **131**, 654-671.  
<https://doi.org/10.1016/j.compstruct.2015.05.077>
- Mohammadimehr, M., Mohammadimehr, M.A. and Dashti, P. (2016), "Size-dependent effect on biaxial and shear nonlinear buckling analysis of nonlocal isotropic and orthotropic micro-plate based on surface stress and modified couple stress theories using differential quadrature methods", *Appl. Mathe. Mech.*, **37**(4), 529-554.  
<https://doi.org/10.1007/s10483-016-2045-9>
- Mohammadimehr, M., Navi, B.R. and Ghorbanpour Arani, A. (2017), "Dynamic stability of modified strain gradient theory sinusoidal viscoelastic piezoelectric polymeric functionally graded single-walled carbon nanotubes reinforced nanocomposite plate considering surface stress and agglomeration effects under hydro-thermo-electro-magneto-mechanical loadings", *Mech. Adv. Mater. Struct.*, **24**(16), 1325-1342.  
<https://doi.org/10.1080/15376494.2016.1227507>
- Mohammadimehr, M., Emdadi, M., Afshari, H. and Roustavi Navi, B. (2018a), "Bending, buckling and vibration analyses of MSGT microcomposite circular-annular sandwich plate under hydro-thermo-magneto-mechanical loadings using DQM", *Int. J. Smart Nano Mater.*, **9**(4), 233-260.  
<https://doi.org/10.1080/19475411.2017.1377312>
- Mohammadimehr, M., Mohammadi-Dehabadi, A.A., AkhavanAlavi, S.M., Alambeigi, K., Bamdad, M., Yazdani, R., Hanifehlou, S. (2018b), "Bending, buckling, and free vibration analyses of carbon nanotube reinforced composite beams and experimental tensile test to obtain the mechanical properties of nanocomposite", *Steel Compos. Struct., Int. J.*, **29**(3), 405-422.  
<https://doi.org/10.12989/scs.2018.29.3.405>
- Navi, B.R., Mohammadimehr, M. and Arani, A.G. (2019), "Active control of three-phase CNT/resin/fiber piezoelectric polymeric nanocomposite porous sandwich microbeam based on sinusoidal shear deformation theory", *Steel Compos. Struct., Int. J.*, **32**(6), 753-767.  
<https://doi.org/10.12989/scs.2019.32.6.753>
- Nejadi, M.M. and Mohammadimehr, M. (2020), "Buckling analysis of nano composite sandwich Euler-Bernoulli beam considering porosity distribution on elastic foundation using DQM", *Adv. Nano Res., Int. J.*, **8**(1), 59-68.  
<https://doi.org/10.12989/anr.2020.8.1.059>
- Ott, E., Nakagawa, T., Sandoval, H. and Shamsaei, N. (2019), "3 - Qualification and certification of metal additive manufactured hardware for aerospace applications\*", *Additive Manuf. Aerosp. Indust.*, 33-66.  
<https://doi.org/10.1016/B978-0-12-814062-8.00003-0>
- Ou, Y., Yang, F. and Yu, Z. (1998), "A new conception on the toughness of nylon 6/silica nanocomposite prepared via in situ polymerization", *J. Polym. Sci. Part B: Polym. Phys.*, **36**(5), 789-795.  
[https://doi.org/10.1002/\(SICI\)1099-0488](https://doi.org/10.1002/(SICI)1099-0488)
- Pandian, G., Pecht, M., Zio, E. and Hodkiewicz, M. (2020), "Data-driven reliability analysis of Boeing 787 Dreamliner", *Chinese J. Aeronaut.*, **33**(7), 1969-1979.  
<https://doi.org/10.1016/j.cja.2020.02.003>
- Rahman, M.M., Jumaat, M.Z. and Islam, A.B.M. (2017), "Weight minimum design of concrete beam strengthened with glass fiber reinforced polymer bar using genetic algorithm", *Comput. Concrete, Int. J.*, **19**(2), 127-131.  
<https://doi.org/10.12989/cac.2017.19.2.127>
- Rajabi, J. and Mohammadimehr, M. (2019), "Bending analysis of a micro sandwich skew plate using extended Kantorovich method based on Eshelby-Mori-Tanaka approach", *Comput. Concrete, Int. J.*, **23**(5), 361-376.  
<https://doi.org/10.12989/cac.2019.23.5.361>
- Ahuja, T. and Kumar, D. (2009), "Recent progress in the development of nano-structured conducting polymers/nanocomposites for sensor applications", *Sensors Actuat. B: Chem.*, **136**(1), 275-286.  
<https://doi.org/10.1016/j.snb.2008.09.014>
- Saleem, A., Medina, L. and Skrifvars, M. (2020), "Mechanical performance of hybrid bast and basalt fibers reinforced polymer composites", *J. Polym. Res.*, **27**(3).  
<https://doi.org/10.1007/s10965-020-2028-6>
- Salvetat, J.-P., Briggs, G.A.D., Bonard, J.-M., Bacsá, R.R., Kulik, A.J., Stöckli, T., Burnham, N.A. and Forró, L. (1999), "Elastic and shear moduli of single-walled carbon nanotube ropes", *Phys. Rev. Lett.*, **82**(5), 944.  
<https://doi.org/10.1103/PhysRevLett.82.944>
- Shahsavari, D., Karami, B. and Janghorban, M. (2019), "Size-dependent vibration analysis of laminated composite plates", *Adv. Nano Res., Int. J.*, **7**(5), 337-349.  
<https://doi.org/10.12989/anr.2019.7.5.337>
- Sheng, N., Boyce, M.C., Parks, D.M., Rutledge, G.C., Abes, J.I. and Cohen, R.E. (2004), "Multiscale micromechanical modeling of polymer/clay nanocomposites and the effective clay particle", *Polymer*, **45**(2), 487-506.  
<https://doi.org/10.1016/j.polymer.2003.10.100>
- Soleymani, T. and Arani, A.G. (2019), "On aeroelastic stability of a piezo-MRE sandwich plate in supersonic airflow", *Compos. Struct.*, **230**, 111532.  
<https://doi.org/10.1016/j.compstruct.2019.111532>
- Tayeb, T.S., Zidour, M., Bensattalah, T., Heireche, H., Benahmed, A. and Bedia, E.A. (2020), "Mechanical buckling of FG-CNTs reinforced composite plate with parabolic distribution using Hamilton's energy principle", *Adv. Nano Res., Int. J.*, **8**(2), 135-148.  
<https://doi.org/10.12989/anr.2020.8.2.135>
- Unnikrishnan, V.U., Unnikrishnan, G.U. and Reddy, J.N. (2011), "Multiscale analysis of carbon nanotube-reinforced nanofiber scaffolds", *Compos. Struct.*, **93**(2), 1008-1014.  
<https://doi.org/10.1016/j.compstruct.2010.06.019>
- Wang, D. and Bierwagen, G.P. (2009), "Sol-gel coatings on metals for corrosion protection", *Progress Organic Coat.*, **64**(4), 327-338.  
<https://doi.org/10.1016/j.porgcoat.2008.08.010>
- Wang, S., Chen, F., Xue, Q. and Zhang, P. (2020), "Splitting tensile strength of cement soil reinforced with basalt fibers", *Materials*, **13**(14), 1-15.  
<https://doi.org/10.3390/ma13143110>
- Wen, J. and Wilkes, G.L. (1996), "Organic/inorganic hybrid network materials by the sol-gel approach", *Chem. Mater.*, **8**(8), 1667-1681.  
<https://doi.org/10.1021/cm9601143>
- Wu, H., Fahy, W.P., Kim, S., Kim, H., Zhao, N., Pilato, L., Kafi, A., Bateman, S. and Koo, J.H. (2020), "Recent developments in

polymers/polymer nanocomposites for additive manufacturing”,  
*Progress Mater. Sci.*, **111**, 100638.

<https://doi.org/10.1016/j.pmatsci.2020.100638>

Yang, G., Park, M. and Park, S.-J. (2019), “Recent progresses of  
fabrication and characterization of fibers-reinforced composites:

A review”, *Compos. Commun.*, **14**, 34-42.

<https://doi.org/10.1016/j.coco.2019.05.004>

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