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RESEARCH IN CARBON-CARBON COMPOSITES

saifeldein a. arabab
saisu@siu.edu

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RESEARCH IN CARBON-CARBON COMPOSITES

By

Saifeldein Arabab

B.Sc., University Of Khartoum- Sudan

A Research Paper

Submitted in Partial Fulfillment of the Requirements for the
Master of Science Degree

Department of Mechanical Engineering and Energy Processes

in the Graduate School

Southern Illinois University Carbondale

May 2015

PAPER APPROVAL

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Approved by:

Dr. Jarlen Don, Chair

Dr. Rasit Koc

Dr. Peter Filip

Graduate School

Southern Illinois University Carbondale

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AN ABSTRACT OF THE RESEARCH PAPER OF

SAIFELDEIN ARABAB, for the MASTER degree in MECHANICAL ENGINEERING & ENERGY PROCESSES, presented on 3rd of April, 2015 at Southern Illinois University Carbondale.

TITLE: CARBON-CARBON COMPOSITES

MAJOR PROFESSOR: Dr. Jarlen Don

Carbon-Carbon (C-C) composites, are materials that offer designers a significant importance over conventional materials for advanced applications. The Carbon-Carbon (C-C) composites were originally developed to be used in aerospace and defense applications, because of their unique properties. Currently, they are employed in many applications. They exhibit light weight, high thermal efficiency, and excellent mechanical properties at higher temperatures, making them the right candidate materials for aircraft and racing car brakes and re-entry nose tips. Moreover, they demonstrate significant durability for friction and wear properties. Compared to advanced ceramics, Carbon-Carbon (C-C) composites have improved thermal and mechanical properties along with high friction coefficient and low wear [1-2]. Due to its remarkable properties, carbon-carbon composites display high dimensional stability at elevated temperatures greater than 3000°C without major deformation, while other materials such as a wide range of metals experience drastic deterioration. The properties of Carbon-Carbon (C-C) composites are very much dependent on the manufacturing methods used for production. Although the general production technology is known, the combination of processes to achieve specifically tailored properties remains the expertise of particular manufacturers. This study represent a review of some major developments in Carbon-Carbon (C-C) composites including properties, major applications, and future potential [3]. Improving structural components and elements by various techniques such as matrix reinforcements along with decreasing of manufacturing costs make

this family of materials more and more attractive to a variety of engineering applications, especially high performance applications.

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1.0 Introduction

Composite materials are made of a combination of two or more materials with different mechanical, chemical or physical properties. Like all other composite materials, Carbon-Carbon (C-C) composites combine two major elements, carbon fibers and a carbon matrix. The properties of Carbon-Carbon (C-C) composites are significantly improved and more appropriate for many applications. Carbon-Carbon (C-C) composites are preferred over other materials because they maintain stability and perform structurally at highest temperature due to light weight, strong stiffness, toughness, superior thermal coefficients, ablation, and high-speed friction properties. The components of Carbon-Carbon (C-C) have been manufactured in the United States in the last three decades for most aerospace and defense applications. Carbon-Carbon (C-C) composites combine exceptional mechanical property-to-weight ratios and excellent refractory properties, making them the materials of choice for severe and tough environmental applications such as atmospheric reentry, solid rocket motor exhaust, and disk brakes in high performance military and commercial aircrafts, high speed trains and racing cars [4].

1.1 Background & Early Development

Carbon-Carbon (C-C) composites are a new class of materials made by arrangement of several components together to create a product that is stronger than the sum of their constituents. The significant usefulness of (C-C) composites come from their high and enhanced properties compared to other materials.

The early forms of composite materials were found in 1500 BC by the Egyptians. They made their structures and houses using composite bricks created out of mud and straw as presented in figure 1 to be stronger and to generate compressive forces that allow them to better adhere

together increasing the structural integrity of their buildings. In 1200 AD, Mangoes created composite bows made out of wood and animal bone. At the time they were the most powerful weapons on the face of the planet until guns were invented. A picture of the Mangoes bows is shown in figure 2. In 1936, Ray Greene from Toledo, Ohio, created the first composite sailing dinghy made out of a polyester resin. The 16 foot boat started downstream marine boating, and today it is still made with polyester along with fiber glass. In 1958, composite materials were first employed in Chance Vought Aircrafts by Brennen Foch. In 1970, the back stabilizer fans in the F-14 Tomcat aircraft presented in figure 3 were manufactured using 2% of carbon fiber composites. In 1981, the carbon fiber mono car, also known as the driver compartment, was developed and introduced in the Formula 1 racing car. This was considered as one of the greatest significant contributions to safety in the Formula 1 racing since its beginning in the early 1950s. Fast forwarding, the Boeing 787 Dreamliner is made out of 50% composites compared to the 1970 2% composites aircraft. The Boeing 787 Dreamliner presented in figure 4 is the lightest aircraft on earth [17].



Figure 1-1: Composite bricks made out of straw and mud [17].



Figure 1-2: The composite bows [17].



Figure 1-3: F-14 Tomcat: one of the first aircraft using carbon composites [17].

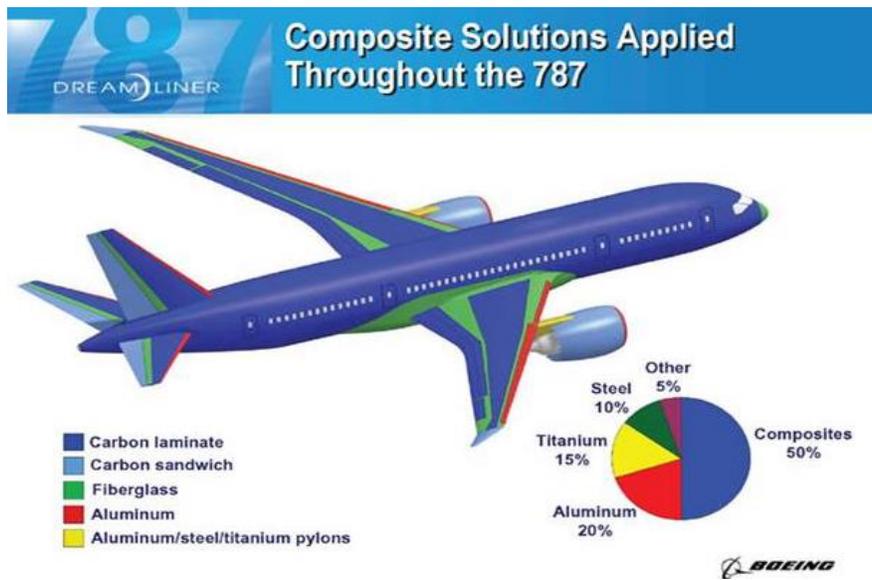


Figure 1-4: The Boeing 787 Dreamliner 50% of composites [17].

2.0 Components of (C-C) Composites

Carbon-Carbon (C-C) composites are well known by their remarkable properties. These properties depend on a selected set of components and how they are arranged and coordinated. The matrix phase and the fibers phase are known as the two major elements of a carbon composite structure. These elements can be in many different forms, for example fibers can be in the form of single strands, abundant strands or plaited. The direction and the layering of the chosen fiber is the controlling function in determining the characteristics of the achieved composite frame. The matrix system play a significant sole in the composite structure. Matrix system is responsible for holding the fibers in their required location and transferring the load and stress between the fibers. It also acts as a barrier from adverse environment and helps protect the fibers from mechanical abrasion. The matrix also provides significant enhancement in many mechanical properties, making the composite structure very strong compared to a single conventional material.

Carbon-Carbon (C-C) composites are leading most of the composite materials in preserving the mechanical properties such as toughness and high strength at high temperatures over 3000°C [5, 6]. Diamond, graphite, fullerenes are the three allotropic forms of the carbon used in Carbon-Carbon (C-C) composites. Any type of these carbon forms has its own important use in manufacturing and industrial fields. Graphite can be available in large quantities and in different forms with estimated density of 2.2 g/m³. Carbon materials possess very high specific strength of almost 50 GPa and maintain this high strength at elevated temperatures of more than 1500°C. The extraordinary mechanical and thermal properties of carbon are due to the strong covalent bond between the atoms in the carbon materials [7, 8]. Researchers have discovered and realized the high strength of carbon materials and their potential use. This, coupled with the need for high

performance reinforcing fibers for improved composites, have led to the development of Carbon-Carbon (C-C) composites [9]. Carbon-fiber-reinforced-carbon matrix composites (FRC) known as Carbon-Carbon (C-C) composites are a type of composite materials consisting of carbon fiber reinforced with graphite matrix. Carbon-Carbon (C-C) composite has many advantages compared to other composite materials or metals, especially in the thermal expansion properties. Carbon -Carbon (C-C) composites can absorb heat without deformation because of its low coefficient of the thermal expansion in the fiber direction (0.3-0.5mm) and (0.5-0.8mm) in the perpendicular direction, and wear rates (0.05-0.1mm) and (0.1-0.3mm) in the fiber direction and perpendicular direction, respectively. When a load is applied to the composite, first it will be applied over the matrix phase, then it will be transferred and distributed to the reinforcement phase, which lead to an increase in the overall strength of the composite. The physical properties of Carbon-Carbon (C-C) composites are dominated by the reinforcing fibers [10].

2.1 Composites material groups

1- Graphite fiber reinforcement plastic (GFRP) and aramids (Kevlar) are the common used of the fibers.

2- Polymer matrix composite (PMC) and fiber reinforcement plastic (FRP) are known as Reinforced Plastics. In all of the groups above the fibers have high specific stiffness (stiffness to weight ratio) and high specific strength (strength to weight ratio), percentage can reach up to 80% of reinforced plastic, the matrix materials always are fluorocarbon, silicon, phenolic, and thermoplastics. Fibers can be arranged inside the composites as form of particles (large particles

or dispersion) short, long, continuous, or discontinuous (random or aligned) as it shows in the figure below

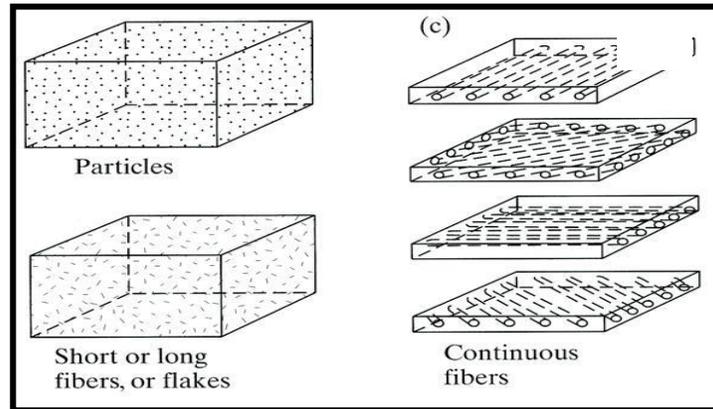


Figure 2-1: The fiber arranged inside the composite [8].

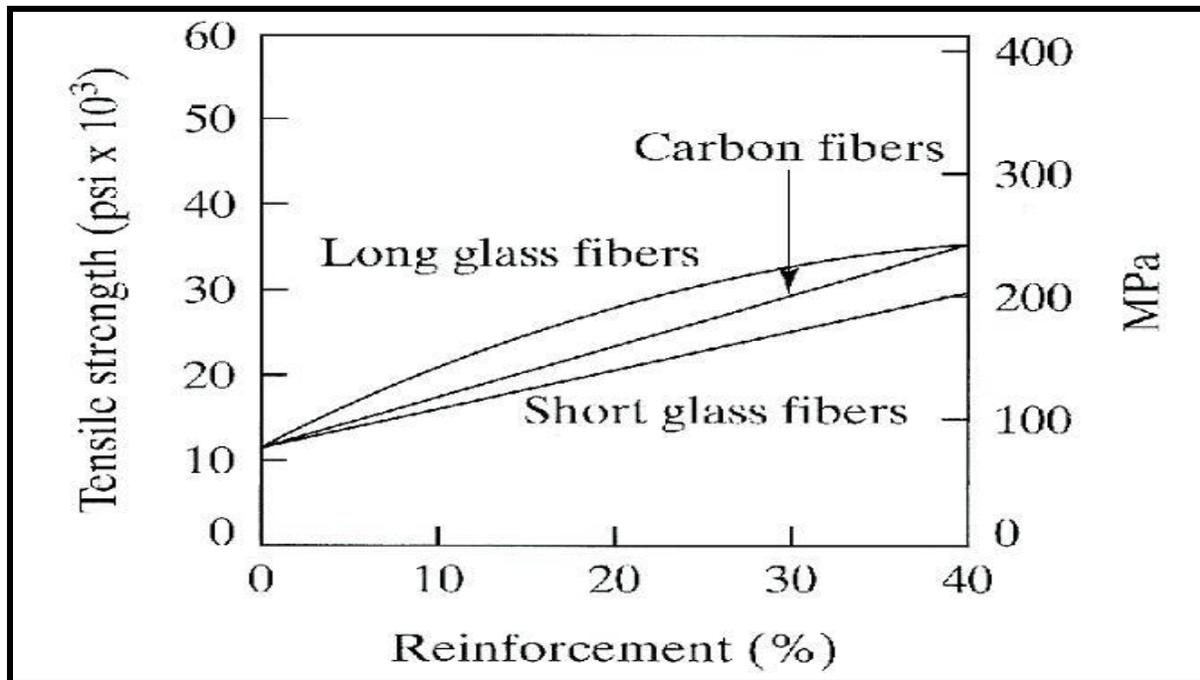


Figure 2-2: The figure shows the Reinforcement percentage and tensile strength for different types of composites. [9].

2.2 There are some factors that can change the mechanical properties of the reinforced fibers composite:

- 1-The direction of the reinforcing material can be unidirectional, orthogonal, or random.
- 2-The kind of the fibers long- short glass and carbon fiber.
- 3- Relative volume shape, and the length of the fibers.

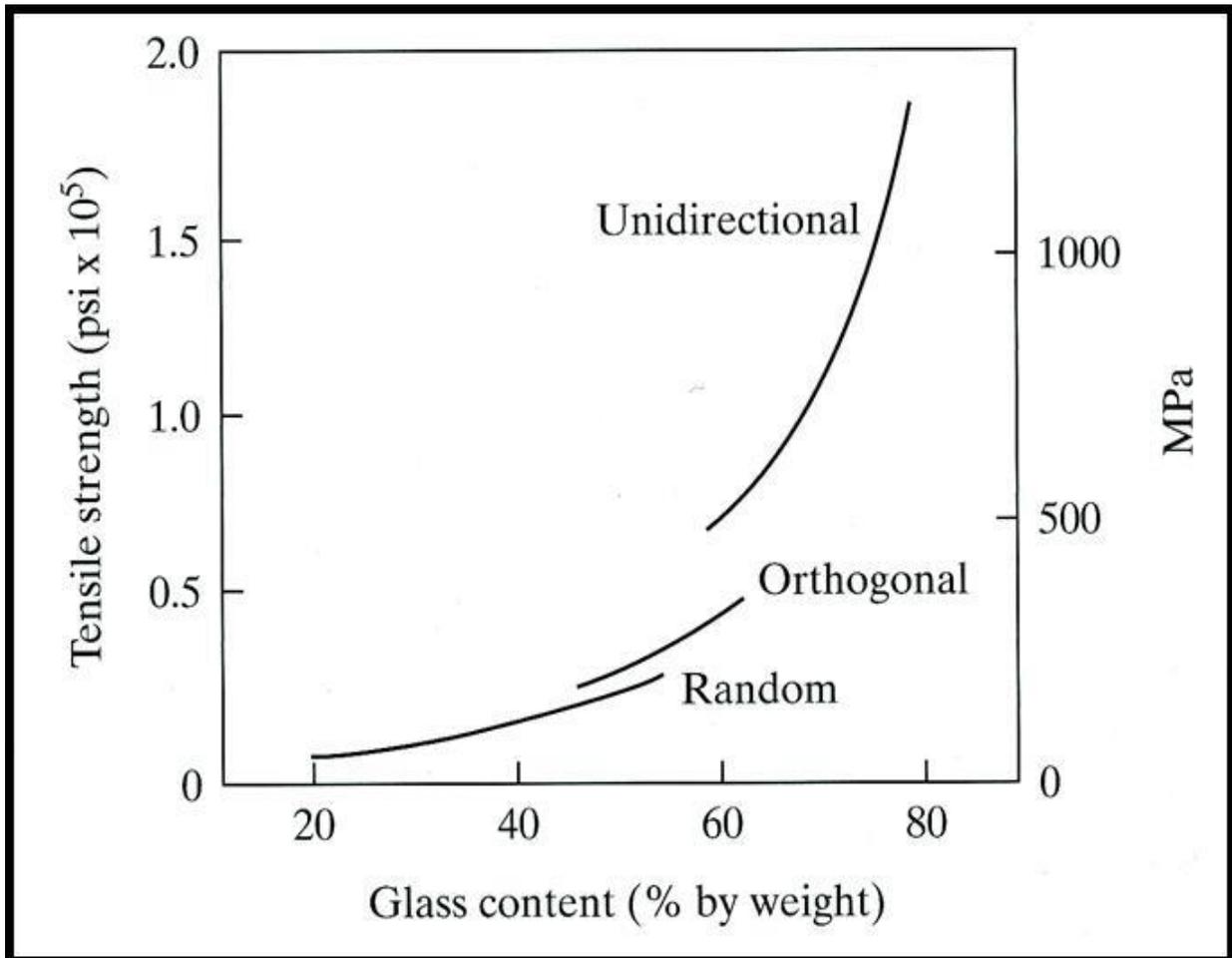


Figure 2.2-1: The volume vs. tensile strength ,and the orientation of the fibers in reinforced plastic [10].

3.0 Carbon-Carbon (C-C) Composites Properties

Carbon- Carbon(C-C) composites are able to adapt or be adapted to many different functions or activities. Carbon- Carbon (C-C) composites have significant properties compared with the conventional materials or ceramic composites. These properties make the composites the materials of choice for severe environmental applications. The properties of interest are chemical, physical, mechanical, and manufacturing. These properties depend on the specific design of the desirable application.

The following properties are some of the advantages of carbon -carbon composites over other materials.

3.1 Chemical Properties:

1-Carbon- Carbon (C-C) composites are fire resistance non flammable materials that can be used in applications requiring high heat resistance such as gas tank and some medical devices.

2- Carbon- Carbon (C-C) have high resistant to corrosion and oxidation, because they are completely inert materials even in severe environmental conditions.

The properties above are important factors to be considered in most of the applications.

3.2 Physical properties:

1- Carbon- Carbon (C-C) composites are designed in ideal thermal expansion and heat conductivity to be similar to surrounding structures to reduce the thermal stress to the lowest value.

2- Carbon- Carbon (C-C) composites are structured to absorbing or transmitting magnetic and electrical energy. Some military aircrafts are made out of carbon composites absorb radar signals.

3-The melting point and specific heat of Carbon- Carbon composites are significantly higher than other materials whose properties fail or melt, which is why carbon composites are the best materials for high temperature application such as reentry nose tips and aerospace parts.

3.3 Mechanical Properties:

The mechanical properties of Carbon- Carbon (C-C) composites remain higher especially at temperatures over 3000c°, where other materials show weakness and breakdown. By using the fibers in the through- thickness direction that lead to increased thermal transport, strength, and modulus of the carbon- carbon composites [11].

Carbon- carbon composites have high mechanical properties such as:

- 1- Higher strength and lighter materials five times lighter than steel and three times lighter than aluminum. The strength to weight ratios (stiffness) are important in aerospace and automotive applications.
- 2- Resistance to degradation in high fatigue applications much better than conventional materials.
- 3- Capability and ability of ductility, hardness, elasticity, creep, and fracture toughness.

3.4 Manufacturing Properties:

The desirable application cannot be achieved unless the manufacturing processes are finished in the right way. The following points should be considered:

- 1- Formability it is easily formed into complex shapes (ductility) and flexibility.
- 2- Casting is a process by which carbon- carbon composites are shaped by pouring into a mold that contains the negative impression of a desired shape. This process allows the composites to absorb any forceful or impact loads.
- 3- Weldability and machinability very important in service life (durability) even in harsh operating environments.

4.0 Applications

4.1 Applications and Technological Importance

Many of the Carbon- Carbon (C-C) composites currently being produced are in the form of components for missiles and military aircraft. The most important applications include reentry bodies, rocket nozzles, exit cones for strategic missiles, and brake discs for military aircraft. Recently, a commercial aerospace application, where brake discs for transport aircraft will be coated, has become prominent. Carbon- Carbon (C-C) composites are used for the nose tip and wing leading edges on the Shuttle Orbiter vehicles. Present industrial applications for Carbon- Carbon (C-C) composites, such as hot glass handling tools and hot press dies and pistons, are minor compared with the uses in defense and aerospace. The use of Carbon- Carbon (C-C) composites brake discs on commercial transport aircraft has become a significant business, and is expected to grow in the coming years [13]. It is more difficult to predict the future for Carbon- Carbon (C-C) composites especially in the advanced military applications, because the materials are developmental and the projected systems must continue to receive government funding. Specific advanced military applications include hot section components for limited-life missile engines, exhaust parts for new fighter aircraft, hypersonic vehicle fuselage and wing components, and structures for space defense satellites. Commercial non-aerospace applications for Carbon- Carbon (C-C) composites are minor at this time because of the high cost of the material. Expanded use of Carbon- Carbon (C-C) composites in industries other than defense and aerospace will likely require the development of methods that reduce cost and yet maintain properties that provide performance advantages. Potential near-term uses that have been identified are high-speed train and special automobile brakes and clutches, forging dies and molding crucibles, corrosive chemical reactors and heat exchangers, fuel cells, high thermal

conductivity electronic substrates, prosthetic devices, and components for internal combustion engines. More distant large-scale applications include plasma limiters for nuclear fusion devices and inert gas ducting and heat exchangers for gas-cooled fission reactors.

4.2 Aircraft Brakes

Almost 63% of the produced Carbon-Carbon (C-C) composites are used in aircraft brakes all over the world. The brake discs are required to provide the frictional torque which stops the aircraft. The heat generated is very high and acting as a structural component, the surface and frictional temperatures between the rotor and stationary disc are 500 °C, 2000 °C respectively. Due to all of above Carbon-Carbon (C-C) composite is the only material that can be selected because of it is high thermal conductivity and very low coefficient of thermal expansion [14]. The heat capacity of Carbon-Carbon (C-C) composite brakes are 2.5 times greater than steel, Carbon-Carbon (C-C) composite brakes are 300 kgs lighter than steel.

4.2.1 Carbon-Carbon (C-C) composites used in braking systems:

1. Carbon fabric laminates.
2. Semi-random chopped carbon fibers (Hitco).
3. Laminated carbon fiber felts with cross reinforcement (SEP).

4.2.2 The two methods to prevent oxidation during braking:

1. It is achieved by applying a trowel glass forming block to the active sides on non-rubbing surfaces.
2. Adding an inhibitor during fabrication.



Figure 4-1: Shows 787 Dream Liner Brake[14].



Figure 4-2: Shows rotor made of carbon carbon composites in airplane brake disk [14].

4.3 Racing Car Brakes

These kinds of brakes are used in sport cars. Carbon -carbon (C-C) composite brakes were introduced into formula 1. The brakes are operated by hydraulic calipers pressing the Carbon- Carbon (C-C) pads against the ventilated disc.

4.3.1 There are some conditions that must be considered when operated these brakes:

- 1- Each disc required at least 70 cm² of air.
- 2- To avoid the thermal problems, the bell must be made of titanium or aluminum alloy 2618, and its surface to enhancement of hardness and resistance to the high temperature.
- 3- To achieve the high performance temperature must be between 400 C° and 600 C°. Temperatures below 400 C° would increased the friction coefficient and cause low performance, temperature higher than 600 C° would cause excessive oxidation[18].
- 4- Brakes must warm up to develop an optimum friction surface.



Figure 4-3: Formula1 brake disk made of carbon -carbon composites [15].

4.4 Other braking applications

There are many advantages of using Carbon- Carbon (C-C) composites as braking materials such as lightweight applications, inertness with other materials, and high thermo mechanical performance. Carbon-Carbon (C-C) composite brakes have an ability to absorb much energy in a short period of time compared with other materials such as a metal or organic brakes.

Aircrafts, trains, and racing cars prefer Carbon -Carbon(C-C) composites are a metal alternative because Carbon- Carbon (C-C) composites reduce friction by using materials that perform at lower weight. Also the low density of Carbon- Carbon (C-C) coupled with tendency towards lower cost make it ideal for applications in transport or machinery. Carbon- Carbon (C-C) composite brakes have the most improved air portability and give high efficient distribution of the vehicle's weight into the area [15]. These emergency brakes are particularly effective, especially in high momentum situations, when stopping large trucks or trains over short distances and when avoiding injury and damage because of the failure of lifting gears in main shafts. There are some disadvantages of using Carbon- Carbon (C-C) composites in the braking materials, such as the cost, which; can be considered prohibitive for use in domestic vehicles; oxidation, which occurs preferentially in the matrix phase; and its inherence to all Carbon- Carbon (C-C) applications.

5.0 Design and optimization of Carbon- Carbon (C-C) friction members

There are four major classifications of measurement or judgment for preferred fiber orientation within Carbon- Carbon (C-C) brake disc, it's determined by heat flow.

1. Diffuses or discharges the heat away from friction surface and inside the brake disc.
2. Heat can discharge radially.
3. The slot machine must withstand shear force.
4. The effectiveness of the drive slot could reduce to the minimum.

5.1 The development of improvement of Carbon- Carbon (C-C) materials

There are some factors that help to improve Carbon- Carbon (C-C) composite materials:

1. The high thermal conductivity required must be perpendicular to the friction surface.
2. One of the reasons of the enhancement of Carbon- Carbon (C-C) material is that static coefficient of friction must remain in an increased position.
3. An improvement in Carbon- Carbon (C-C) material would be by lowering the costs, and high specific strength of Carbon- Carbon (C-C) materials is a good example for improvement and enhancement.
4. A great prevention of failure[19].



Figure 5-1: The figure shows some applications use carbon-carbon composites [18].

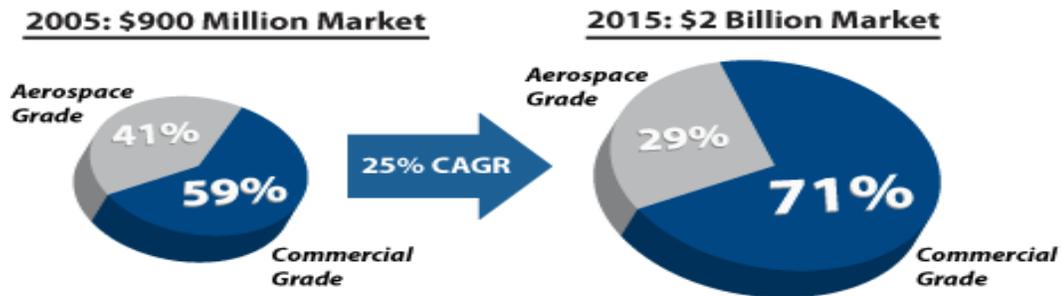


Figure 5.1.2: The figure shows the future of Carbon-carbon composites in ten years [16].

| Global Carbon Fiber Production Demand, by Market, 2012-2020 | | | | | | | | | |
|-------------------------------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|---------|
| Market | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| <i>metric tonnes</i> | | | | | | | | | |
| Aerospace | 7,800 | 9,220 | 11,550 | 13,090 | 13,670 | 14,340 | 16,260 | 18,100 | 19,570 |
| Consumer | 9,990 | 10,280 | 10,530 | 11,110 | 11,790 | 12,410 | 12,770 | 13,110 | 13,730 |
| Industrial | 29,430 | 33,060 | 38,370 | 43,280 | 49,280 | 51,380 | 58,130 | 63,100 | 69,160 |
| Total | 47,220 | 52,560 | 60,450 | 67,480 | 74,740 | 78,130 | 87,160 | 94,310 | 102,460 |

Figure 5.1-3: Shows the global carbon fiber production from 2012 to 2020 [16].

6.0 Conclusion & Future

Carbon- Carbon (C-C) composites are a rare group of composite materials that continues to use its properties to the maximum temperatures, lightest weights, inertness, and high degree of toughness compared with other materials. These properties make Carbon- Carbon (C-C) composites perfect for the most advanced applications in the mechanical engineering fields. The disadvantages that limit the distribution and development of Carbon- Carbon (C-C) composites are fabrication processes use are extremely inefficient, and oxidation is fast in an atmosphere at temperature over 400C°. The cost of Carbon- Carbon (C-C) composite varies, but is well in excess. In military applications, high premiums are paid for improved performance rather than price. Carbon- Carbon (C-C) composites businesses predict increases in the next decade in materials usage. Carbon- Carbon (C-C) composites used in the commercial sectors as brakes, heat exchangers, and furnace elements are restricted by cost, unlike in military fields as rocket components, jet engine parts, and brakes. Carbon- Carbon (C-C) composites will remain the highest performance materials through the coming years [16]. It is uncertain there a sufficient reduction in price or advance in technology in the next years to carry Carbon- Carbon (C-C) into a large area of use. The future of Carbon- Carbon (C-C) composites are very obvious in many different industries especially in wind turbines, compressed natural gas storage and transportation, and fuel cells. Also Carbon- Carbon (C-C) composite has a bright future in fuel efficient automobiles. It is currently used in small production, high performance automobiles, but moving toward large production series cars. The future of Carbon- Carbon (C-C) extends to use in very high demand on construction and infrastructure, for example in the technology of earthquake protection and light weight pre-cast concrete. Carbon- Carbon (C-C) composites have a great future in the oil industry especially in kill lines, drill pipes and deep sea drilling platforms.

If the manufacturers of Carbon- Carbon (C-C) composites apply some of these conditions, the industry will reach its vast potential. There are some conditions reducing the costs by focusing and developing new technology, changing the view of the supplier's cost and future strategy, and sharing the momentum of the enhancements to help and support the market growth.

REFERENCES

- [1] Savage, G. , 1993, *Carbon-carbon Composites*, Chapman & Hall, USA, pp.178-237.
- [2] Rand, B. Appleyard, S. Yardim,M.,1998 Proceedings of the NATO advanced Study Institute on Design and Control of Structure of Advanced Carbon Materials for Enhanced Performance, pp.177-193.
- [3] Savage, G.M., 1988 *Metals and Materials*, 4,544
- [4] Fabrication of composites, in *handbook of composites*, 1986 vol.4 eds A. Kelly, and S.T. Milieko North-Holland, pp. 111-75.
- [5] Ling, L.X, Jun, L.H, Wen Feng. X, and Zhi. L.K, 2007, “The effect of applied stress on damage mode of 3D C/C composites under bend-bend fatigue loading,”. *Science in China Series E-Technological Sciences*, 50(1), pp. 97-102.
- [6] Li, H.J., 2001, “The effect of applied stress on damage mode of 3D C/C composites under bend-bend fatigue loading Carbon/carbon composites”. *New Carbon Mater*, 16 (2): 79-80.
- [7] Pierson, H. O., 1993, *Handbook of carbon, graphite, diamond and Fullerenes*, 1st ed., Noyes, NJ
- [8] Burchell, T. D., 1999, *Carbon materials for advanced technologies*, Pergamon Elsevier Science Ltd., Oxford, UK, Chap.1
- [9] Fitzer, E., 1989, “Carbon fibers – Present state and future applications in carbon fibers, filaments and composites (eds) J L Figueiredo et. Al. (Kluwer Academic), pp. 3-41.
- [10] Morgan., 2005, *Carbon Fibers and Their Composites*, Taylor and Francis, FL, pp.586-591.
- [11] Rosen, B.W., 1965, “Mechanics of composite strengthening. In: *Fiber composite*

materials,” Proceedings of the American Society for metals. USA, pp. 574–86.

[12] Fitzer, E. and Barger, A. (1971) *Proc. Int. Conf. on Carbon Fiber, their Composites and Applications*, London, paper no. 36

[13] Awathi, S. and Wood, J. L. (1988) *Ceram. Eng.Sci. Proc.* **9**(7-8), 553

[14] Morgan, P., 2005, *Carbon Fibers and Their Composites*, Taylor and Francis, FL, p.1010.

[15] *Devillard, J., Berthier, J., and Clary, J. (1976) Ext.Abs.2nd Int.Carbon Conf., p489*

[16] *Advanced Materials technologies Report 8, Carbon -Carbon Composites*, C. H. Kline& Co.(1987)

[17] Ashbee, K., 1989, *Fundamental Principles of Fiber Reinforced Composites*, Technomic Publishing Company, PA, pp. 201-208.

[18] Tandon, G.P. Pochiraju, K.V. and Schoeppner, G.A. 2008, "Thermo-oxidative behavior of high-temperature PMR-15 resin and composites," *Materials Science and Engineering: A*, 498, 1-2, pp.150-161.

[19] Savage, G. 1997, *Carbon-Carbon Composites*, p197-223, 1st ed, Chapman and Hall, UK, Chap.8.

VITA
Graduate School
Southern Illinois University

Saifeldein Arabab

saifna@gmail.com

University of Khartoum Khartoum-Sudan
Bachelor of Science, Mechanical Engineering, January 1996

Research Paper Title:
CARBON-CARBON COMPOSITES

Major Professor: Jarlen Don