Manufacturing of Composite Material using Ceramic Fiber, Epoxy Resin and Microsilica for Aircraft Applications

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***Abstract*— In this study, epoxy based composite filled with ultra light microsilica is prepared by traditional hand layup method, using ceramic fibre as reinforcement. The effect of various percentages of microsilica is investigated on the tensile strength, compression strength, impact resistance of the composite. The result reveals that, up to 15% addition of microsilica enhanced the mechanical properties. However the addition of microsilica beyond 15% decreases the mechanical properties of the composites. This is mainly because addition of microsilica increases the viscosity of epoxy resin which directly affecting the wettability of fibre. From the past researches it is found that, the addition of microsilica has great positive influence on the thermal stability of the composite.**

Keywords*— Ceramic fiber; Epoxy Resin; Microsilica; Mechanical Testing.

I. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. The two constituents are reinforcement and a matrix. Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement. Due to the high stiffness-to-weight and strength-to-weight ratio, excellent fatigue and corrosion performance, fiber-reinforced polymer composite materials, also known as advanced polymer composites, have demonstrated clear-cut advantages with advanced performance at decreased weight over more conventional metallic materials, in a number of demanding aerospace, wind energy, automotive, infrastructure, and consumer applications. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or a particulate.

Thermal Protection System (TPS) is a shield that protects the aircraft from the severe aerodynamic heating which arises during hypersonic reign flight. TPS consists of various type of material applied externally over the aircraft. During hypersonic flight, surface of the aircraft gets heated up to 1500°C due to aerodynamic heating. Aerodynamic heating is the heating of a solid body produced by the passage of fluid (such as air) over a body such as a meteor, missile, or airplane. To absorb the Aerodynamic heating we are using different types of composites. Ceramic fiber Reinforced Epoxy resin and Microsilica has good thermal and mechanical properties as compared to some other composites.

A variety of reusable TPS concepts are being developed to address the requirements of future Reusable Launch Vehicle (RLV).The TPS used in the present study was corrugated core sandwich Metallic Thermal Protection Systems (MTPS). The corrugated core sandwich structure has more damage tolerant properties and load bearing capacities. It is an Integrated Metallic Thermal Protection System (IMTPS), means withstand both thermal as well as structural loads.

The purpose of the thermal protection system is not only to protect the orbiter from the searing heat of re-entry, but also to protect the airframe and major systems from the extremely cold conditions experienced when the vehicle is in the night phase of each orbit.

II. LITERATURE REVIEW

The rapid development and use of composite materials beginning in the 1940s had three main driving forces.

1. Military vehicles, such as airplanes, helicopters, and rockets, placed a premium on high-strength, light-weight materials. While the metallic components that had been used up to that point certainly did the job in terms of mechanical properties, the heavy weight of such components was prohibitive. The higher the weight of the plane or helicopter itself, the less cargo its engines could carry.
2. Polymer industries were quickly growing and tried to expand the market of plastics to a variety of applications. The emergence of new, light-weight polymers from development laboratories offered a possible solution for a variety of uses, provided something could be done to increase the mechanical properties of plastics.
3. The extremely high theoretical strength of certain materials, such as glass fibers, was being discovered. The question was how to use these potentially high-strength materials to solve the problems posed by the military's demands.

One may conveniently speak of four generations of composites:

- 1st generation (1940s): Glass Fiber Reinforced Composites
- 2nd generation (1960s): High Performance Composites in the post-Sputnik era
- 3rd generation (1970s & 1980s): The Search for New Markets and the Synergy of Properties
- 4th generation (1990s): Hybrid Materials, Nano composites and Biomimetic Strategies
- Summary: The Impact of Composites on Materials Research

Ceramic fiber appeared in United States in early 1940s. However, China hadn't developed the technology of ceramic fiber until 1970s. Due to the undeveloped economy and incomplete industry system, few people were unaware of the ceramic fiber as a new kind of insulation material before 1990s. In 1990s, the energy-saving and thermal insulation technology had been improved with the establishment of Chinese industry system and development of heavy industries.

Epoxy resins were first commercialized in 1946 and are widely used in industry as protective coatings and for structural applications, such as laminates and composites, tooling, molding, casting, bonding and adhesives, and others. The ability of the epoxy ring to react with a variety of substrates gives the epoxy resins versatility. Treatment with curing agents gives insoluble and intractable thermoset polymers.

The history of silica fume is relatively short, the first recorded testing of silica fume in Portland cement based concretes was in 1952 and it wasn't until the early 1970's that concretes containing silica fume came into even limited use. The biggest drawback to discovering the unique properties of silica fume and its potential was a lack of silica fume to experiment with. Early research used expensive additive called Fumed silica, a colloidal form of silica made by combustion of silicon tetrachloride in hydrogen-oxygen furnaces. Silica fume on the other hand, is a by-product or a very fine pozzolanic material, composed of mostly amorphous silica produced by electric arc furnaces during the production of elemental silicon or ferro silicon alloys. Before the late 1960's in Europe and the mid1970's in the United States, silica fume simply went up the stack as smoke vented into the atmosphere.

III. METHODOLOGY

A. Materials

Epoxy resins, most of which are made from bisphenol A(BPA), are essential to modern life, public health, efficient manufacturing and food safety. They are used in a wide array of consumer and industrial applications because of their toughness, strong adhesion, chemical resistance and other specialized properties The properties of the phenolic resin are listed in table 1. Ceramic woven fibre is used as reinforcement. The properties of ceramic woven bidirectional fibre are tabulated in the table 1. Ultra light micro silica was used as filler. Silica fume, also known as microsilica, is an amorphous made up of silicon dioxide. It is an ultrafine powder collected as a by-product of the ferrosilicon and silicon alloy production. The properties of microsilica are listed in the table 1.

TABLE. 1. Properties of Ceramic Fibre, Epoxy resin and Microsilica

Reinforcement: Ceramic fiber	Matrix: Epoxy rein	Filler: Microsilica
Density: 2.7 g/cc GSM: 200gsm Thickness: 0.6mm Constituents: Alumina (<99%) Color : White	Density : 1.3 g/cc Color White Curing Temperature : 175˚C	Density: 0.81g/cc Specific gravity: 2.2 Particle Size: 5 µm(avg) Color: White

B. Specimen Preparation

The composite specimens are manufactured from bi-directional ceramic fibre and ultra light micro silica filled Epoxy resin using traditional hand layup method. The percentage of weight of ultra light micro silica varied from 5% to 20 % in the epoxy resin. Initially, microsilica is mixed with pre calculated epoxy resin. Then this mixture was stirred slowly and thoroughly for about 30 minutes by using handheld electrical stirrer. The composite specimens were prepared consists of 7 layer of bi-directional ceramic fibre using traditional hand layup process. Then curing is done by place this specimen in hot air oven for about 4 hours at the temperature of 175˚C.

- Matrix : Epoxy Resin
- Reinforcement : Ceramic Fibre
- Filler : Micro Silica
- No. of plies: 7 layers
- Filler Concentration: 0%, 5%, 10%, 15% & 20%.
- Curing Temperature : 175°C
- Curing Time : 4 hrs

The ASTM standard based samples for tensile, compression and impact testing were cut from the specimens. Samples for impact testing were notch cut before testing.

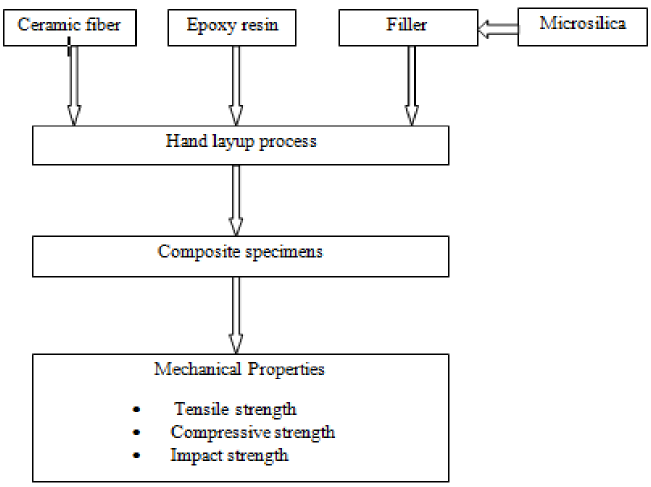

Fig. 1 Methodology involved in making the ceramic composite

IV. CHARACTERIZATION AND TESTING

4.1 Mechanical Properties

The mechanical testing is performed to quantify the effect of the microsilica on the mechanical performance of the microsilica filled composite. Tensile strength and Compression strength were measured at ambient condition using a universal testing machine (Shimadzu's Autograph AG-X Plus 50K Universal testing machine), according to ASTM procedures D638 and D695 respectively; at a crosshead speed of 3 mm per minute for tensile testing and 1mm per minute for compression testing. The tensile strength and compressive strength of the composites filled with various percentage of microsilica are showed in table 2.

TABLE. 2. Tensile strength, Compressive strength and Impact energy absorbed by the composites

Percentage of filler	Tensile test		Compression Test		Energy absorbed during impact load (Charpy) in Joules
	Tensile strength (N/mm²)	Load at peak (KN)	Compressive strength (N/mm²)	Load at peak (KN)	
0%	51.53	7.92	18.85	2.93	4.82
5%	64.21	9.75	23.25	3.62	6.08
10%	68.88	10.32	25.36	3.84	6.86
15%	71.93	10.95	27.21	4.17	7.35
20%	70.12	10.67	26.13	4.06	7.09

Notched Charpy impact strength was determined at ambient condition according to ASTM D256 standard, using Charpy impact tester (Impact Testing Machine AIT-300N). Energy absorbed by the composites filled with various percentage of microsilica is showed in the table 2.

V. RESULTS AND DISCUSSION

A. Mechanical Properties

From the experimental result of tensile test, it is observed that the addition of microsilica with epoxy resin up to 15%, increases the tensile strength of the composite is shown in figure 2. When compare to neat composite, addition of filler from 5 to 15%, tensile strength of the composite increased from 30 % to 55% of the tensile strength of composite filled with no filler respectively. It is also observed that the further addition of microsilica with epoxy resin for about 20% decreases the tensile strength of the composite. The reduction in tensile strength of the composite filled with more than 15% of microsilica may be due to addition of microsilica increases the viscosity of the epoxy resin. The increase of viscosity of the modified epoxy resin decreases the impregnation ability of the epoxy resin. Hence increase of modified epoxy resin the viscosity decreases the wettability of the ceramic fibre, which in turn directly affects the tensile strength of the composite.

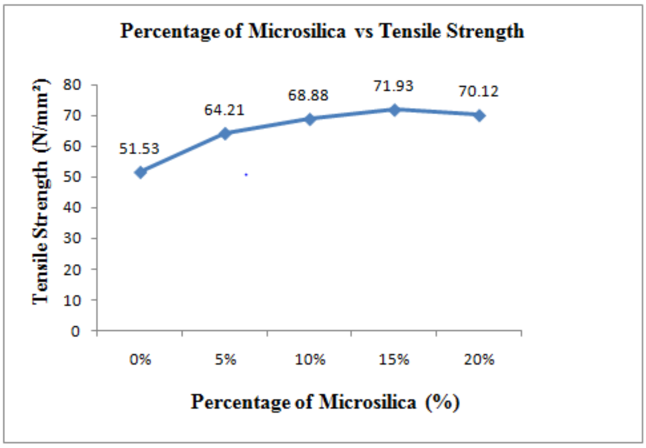

Fig. 2 Influence of microsilica on the tensile strength of the composites

It is found that the compressive strength of composite filled with microsilica increases up to 15% addition of microsilica and beyond the transition limit of 15%, further addition of microsilica decreases the compressive strength of the composites. The compressive strength of the composites filled with various percentage of microsilica is shown in figure 3. Specifically compared to the composite with no filler, compressive strength of 15% and 20% filled composite increased and decreased by 45% and 30% respectively.

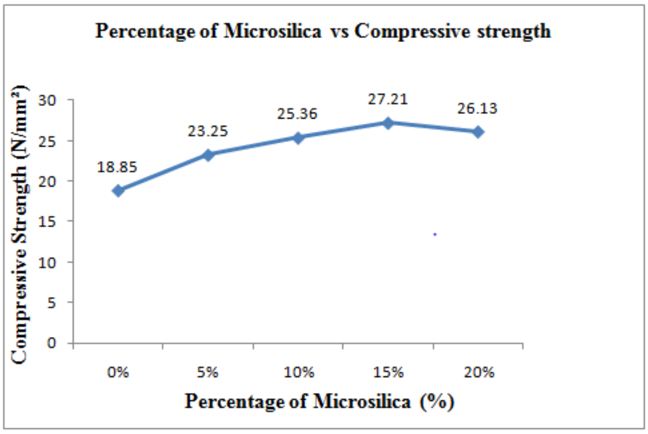

Fig. 3 Influence of microsilica on the compressive strength of the composites

Energy absorbed by the composite filled with various percentage of silica during impact loading (Charpy) is shown in figure 4. Composite filled with 5% of silica absorbed 27% more than the composite filled with no silica. Similarly, the composite with 10% and 15% of silica absorbed 43% and 55% more energy than the composite filled with no silica respectively. This result indicated that the addition of silica with epoxy resin increases the energy absorbing nature of composite when subject to high rate of loading. However, composite filled with 20% of silica, shows decrease in energy absorbing capacity, when to compare to composite filled with 15% of silica. Hence the addition of microsilica beyond the transition limit of 15%, inversely affect the impact resistance of the composite.

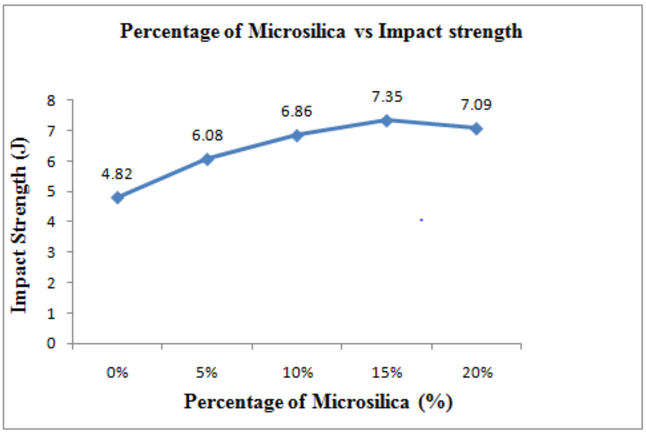

Fig. 4 Influence of microsilica on the impact strength of the composites

B. Comparison between Ceramic Fiber Reinforced Epoxy and Ceramic Woven Fiber Reinforced Phenolic Resin Composites

The Tensile strength of Ceramic fiber reinforced Epoxy resin composite (CFRE) is higher than the Ceramic woven fiber reinforced Phenolic resin composite (CFRP). The use of Epoxy resin in the ceramic fiber increases the tensile strength 5% than the Phenolic resin Composite. This is because of Epoxy resin has high toughness and excellent bonding properties than the Phenolic resin. The comparison chart between CFRP and CFRE is shown in Fig 5.

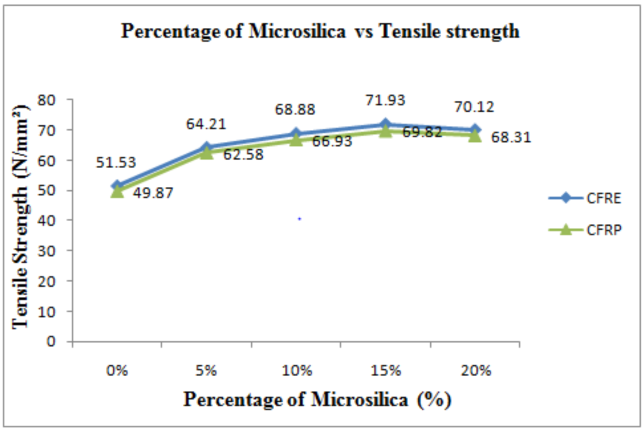

Fig. 5 Influence of microsilica on the tensile strength of CFRP and CFRE composites

The Compressive strength of Ceramic fiber reinforced Epoxy resin composite (CFRE) is higher than the Ceramic woven fiber reinforced Phenolic resin composite (CFRP). The use of Epoxy resin in the ceramic fiber increases the compressive strength 5% than the Phenolic resin Composite. This is because of Epoxy resin has high toughness and excellent bonding properties than the Phenolic resin. The comparison chart between CFRP and CFRE is shown in Fig 6.

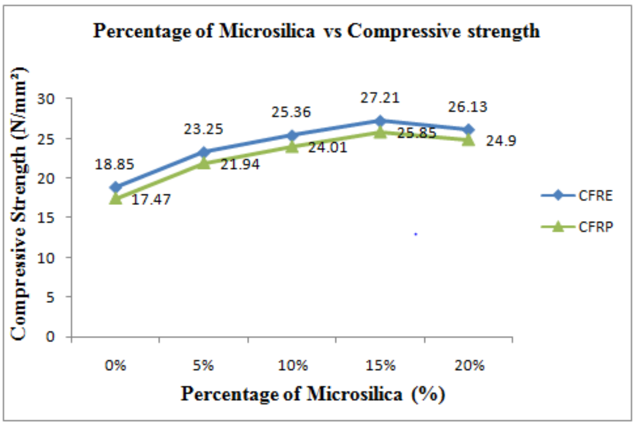

Fig. 6 Influence of microsilica on the compressive strength of CFRP and CFRE composites

The Impact strength of Ceramic fiber reinforced Epoxy resin composite (CFRE) is higher than the Ceramic woven fiber reinforced Phenolic resin composite (CFRP). The use of Epoxy resin in the ceramic fiber increases the impact strength 5% than the Phenolic resin Composite. This is because of Epoxy resin has high toughness and excellent bonding properties than the Phenolic resin.

It is found that the Impact strength of the Ceramic fiber reinforced epoxy resin (CFRE) and Ceramic woven fiber reinforced Phenolic resin (CFRP) composites goes on increases up to 15% of Microsilica. However the addition of Microsilica beyond 15% decreases the impact strength of both the composites. The comparison chart between CFRP and CFRE is shown in Fig 7.

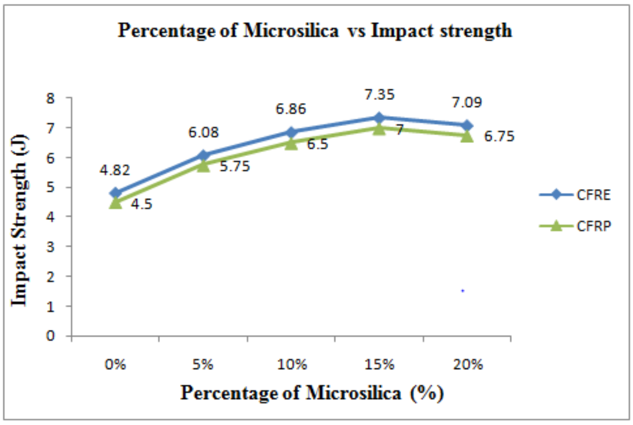

Fig. 7 Influence of microsilica on the compressive strength of CFRP and CFRE composites

VI. CONCLUSION

The addition of microsilica up to 15% with the epoxy resin as filler in the Ceramic fibre / epoxy resin composite increases the tensile strength, compressive strength and impact resistance of the composite. However, the addition of microsilica beyond 15% reduces the tensile strength, compressive strength and impact resistance of the composite due to poor wettability of the fibre. It is also observed that the addition of microsilica with epoxy resin increases the thermal stability of the composite filled with the various percentage of microsilica. It is found that from the past researches the Ceramic Fiber, epoxy resin and Microsilica Composite can withstand the temperatures up to 1400°C.

High temperature Reusable Surface Insulation (HRSI) in aircraft was primarily designed to withstand 1600°C or 2910°F. Low temperature Reusable Surface Insulation (LRSI) is used to withstand the temperatures up to 649°C or 1200°F. So that it is concluded that this composite specimens can be

used in the Aerospace applications because this composite can withstand temperatures up to 1400°C.

ACKNOWLEDGMENT

The author would like to thank the management and HOD of mechanical engineering department, SKIT, for their support and assistance.

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