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DESIGN AND STRUCTURAL ANALYSIS OF COMPOSITE SHAFT FOR AN INDUCTION MOTOR

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Abstract: The thesis is intended to research the composite shaft material in place if conventional shaft material (Carbon steel SAE 1045). Substituting composite structure in place of conventional metallic structure has advantages like higher strength, high specific stiffness and lower density. The Property of composite shaft is used for the applications in which reducing weight is an important factor without compromising the quality and factor of safety. This thesis was carried out for industries in which manufactures Motors and Generators. This thesis aims at providing the less weight composite shaft when compared to the conventional shaft and it will be used in motor which demands lesser overall weight.

***Index Terms* – Aluminium 6061, Aluminium Pure, Aluminium alloy, Metal Matrix Composites, silicon carbide.**

I. INTRODUCTION

Metal matrix composite is a composite material with at least two constituent parts, in which one part is metal and other material, is different metal or another material, such as an organic compound or a ceramic. If there is three materials are present, it is called a hybrid composite. Metal matrix composites are generally made by dispersing reinforcing material into a metal matrix. Here the surface of the reinforcement may be coated with some chemicals into to prevent a chemical reaction with the matrix. For example carbon fibres in the aluminium matrix are coated with either titanium boride or nickel in order to prevent the reaction with aluminium matrix. In aluminium matrix usually carbon fibres are used to synthesize composites which have low density and high strength. The matrix is single material into which the reinforcement is dispersed and is completely continuous. It means that there is a path through the matrix to any point in the material. In most of the structural application the matrix is usually a lighter metal such as magnesium, aluminium, or titanium, and provides a complaint support for the reinforcement. In high-temperature applications, cobalt or cobalt- nickel alloys are mainly used as matrices. In a matrix the reinforcement material is dispersed. The reinforcement always is not used for structural task, but it is mainly used to change the physical properties such to increase the wear resistance, friction coefficient, or thermal conductivity. The reinforcement in the matrix may be either continuous or discontinuous. Discontinuous metal matrix composites can be isotropic, i.e. the orientation is uniform. Also the property varies systematically and it depends on the direction, these can be worked with standard metal working techniques, such as extrusion, rolling, forging. These can be machined using conventional machining techniques but some may require the use of polycrystalline diamond tooling (PCD).The continuous reinforcement can use fibres or monofilament wires such as silicon carbide or carbon fibre. Since the fibres are dispersed into the matrix in a certain direction, thus the structure is an anisotropic in which the alignment of the material affects its strength. Discontinuous reinforcement is made up of shot fibres, or particles or whiskers. Here the common reinforcing materials in this category are alumina and silicon carbide.

II. RESEARCH METHODOLOGY AND TECHNIQUES

To finalize the appropriate composite material and motor for the thesis. To model the shaft and apply boundary conditions The shaft is modelled in solidworks. Since this model is being analyzed in Ansys, the shaft is simplified and all the fillets and chamfers are removed. This model is then imported into Ansys and boundary conditions like the Cylindrical support which symbolizes the bearings, Frictionless support on the face where the bearings are seated, shaft is locked in the tangential direction on the face where the coupling is coupled.

Composite material means that two dissimilar materials are combined together intimately bonded to form integrated structure. Two main segments of composites are matrix and reinforcement, which is continuous and discontinuous. Processing techniques are classified as solid and liquid state processing. The factors considered for processing techniques are application, reinforcement materials and state of matrix. For the current work, In manufacturing of desired composite material is liquid state processing. Methods like infiltration, spray detection, stir casting, etc,. are available in which stir casting method is selected.

Ceramic matrix composites are sometimes technical ceramics or else composite materials. The ceramic fibres are placed inside a ceramic matrix to form a ceramic fibre- reinforced material. The constituents of the ceramic matrix composites are brittle; the fibre-matrix interface is tough due to the effective design, this deflects and arrests the crack and its propagation inside the matrix. The fibrous reinforcement is been prevented from failure. Mainly ceramic matrix composites are used in extreme cases.

2.1. MATERIALS USED

AlSiC, it is a metal matrix composite and it has aluminium as matrix and silicon carbide particles as fibre. The thermal conductivity of the Aluminium Silicon Carbide is very high and it is around (180–200 W/m K), the thermal expansion of the Aluminium Silicon Carbide can be adjusted in order to adjust with other materials such as gallium arsenide particles, silicon or with various ceramics. These components are mainly used in high density multi-chip modules, microelectronics, automobile, and shaft.

The Aluminium matrix will have high amount of dislocations, which is responsible for the strength of the material. These dislocations are introduced during the cooling by the SiC particles, which is resulted but the difference in their thermal expansion coefficient

There are different variants of Aluminium Silicon carbide

AlSiC-12 – This composite consists of 63 % of Aluminium alloy and 37 % of the fibre i.e. silicon carbide. The thermal conductivity of this metal matrix composite is 170-180 W/mK. Density of this composite at 25 °C is 2.89 g/cm3

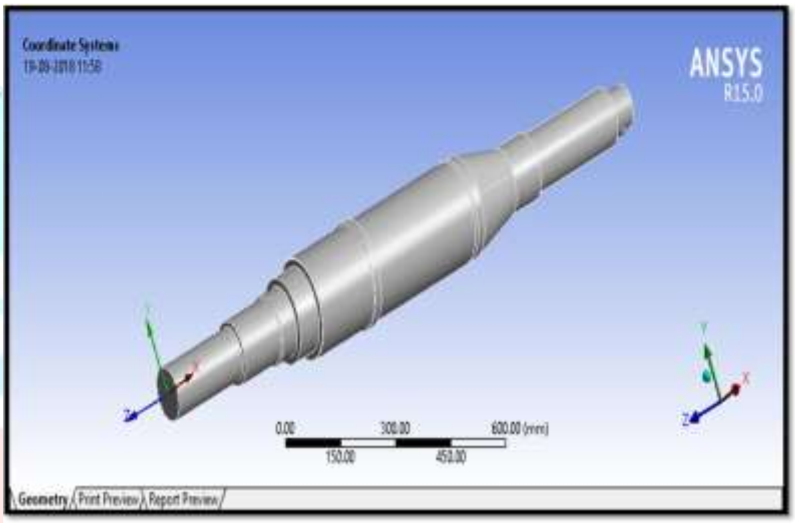
AlSiC-10, it contains 45% of Aluminium alloy and 55% of Silicon Carbide. The density of this component at 25 °C is 2.96 g/cm3. The thermal conductivity is around 190–200 W/m K. The thermal expansion of the component is equal to Duroid. The density of AlSiC-10 is slightly greater than that of AlSiC-12.

AlSiC-9, the volume percentage of aluminium alloy is about 37% and silicon carbide is about 63%. Its density at 25 °C is 3.01 g/cm3. The thermal conductivity of the AlSiC-9 is around 190-200 W/mK. The thermal expansion matches with silicon, alumina, silicon nitride and Bonded copper. The thermal expansion also matches with some co-fired ceramics with low temperature.

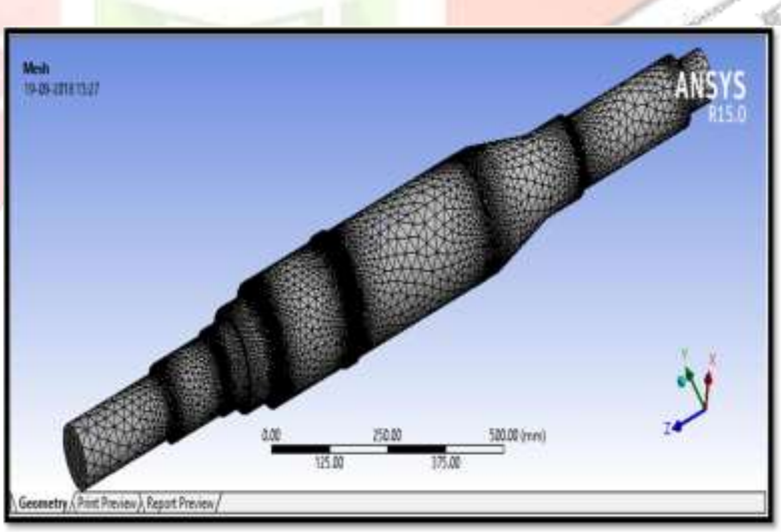
III. DATA ANALYSIS

3.1 Modelling of the composite shaft

The shaft has been modeled in Solidworks Version 16 and the same has been imported for all the analysis done in ANSYS workbench Version 15.

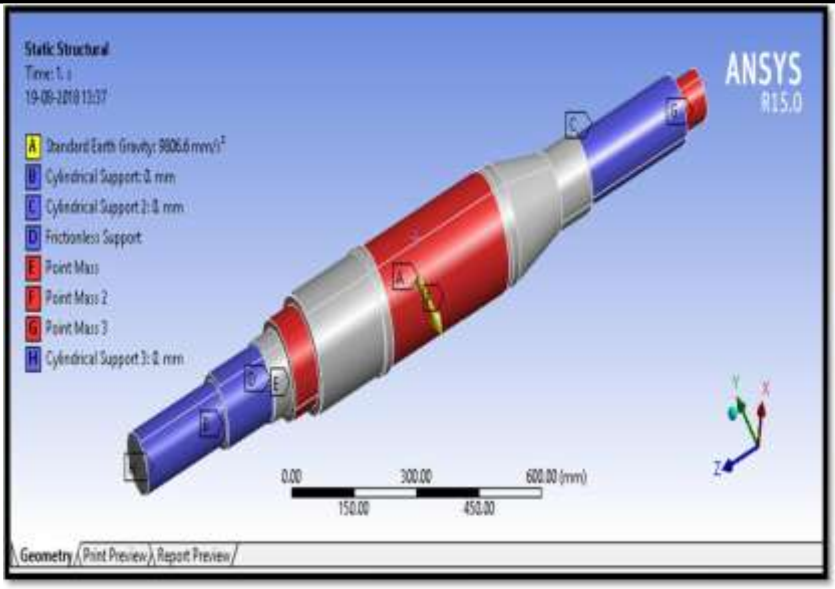


3.2 Mesh Details Mesh Details



3.3 Boundary Conditions for composite shaft

Sl No.	Type of support	Constraint	Location
B.	Cylindrical	Radial	Drive end Bearing Seat
C.	Cylindrical	Radial	Non-Drive end Bearing seat
H.	Cylindrical	Tangential	Coupling
D.	Frictionless	Face	Drive end Bearing Seat



IV MANUFACTURING METHODS

4.1 Stir casting method

The main process used for fabrication of aluminium matrix composite is Stir casting. This is an economical process. Many parameters are there in this process which affects the final microstructure and mechanical properties of the composites. The SIC is used as fiber and they are used as reinforcement to fabricate Al-3 wt.% SiC composites at two different casting temperatures i.e. 680 and 850 °C and the stirring periods are about 2 and 6 min. Factors of reaction at ceramic/matrix interface, ceramic incorporation, porosity, and agglomeration of the particles were taken into consideration by using High-resolution transition electron microscope and scanning electron microscope. In-order to achieve proper metal/ceramic interface it is required for shorter stirring period. To have improved ceramic incorporation the stirring temperature should be high (850 °C). There are some cases, where the shrinkage porosity and intensive formation of Al_4C_3 at the metal/ceramic interface are also observed. At the final stage the mechanical properties of the composites were evaluated, and their relation with the corresponding microstructure and processing parameters of the composites are evaluated.

Interaction between Aluminium matrix and SiC particles

In the furnace when the temperature is from 657 to 827°C, SiC interacts withthe matrix called Aluminium this happens due to dissolution-precipitation process. The mechanism involved in this process is that the carbon atoms migrate from the places aluminium is in direct contact with the SiC faces of Al_4C_3 crystals which are placed close to the Aluminium Silicon carbide interface. The composite so formed can have detrimental influence on the brittle compound Al_4C_3 and also it reduces the strength and ductility, The moisture in the ambient and the liquid water reacts with the composite formed, which debilitating even more the composite.

$4\,Al + 3\,SiC = Al_4C_3 + 3\,Si$

The above reaction is thermodynamically possible since the standard free energy change for this reactive is not positive and Si , Al_4C_3 are the two major products of this reaction. In the chemical reaction the migration of carbon atoms happens which leads to bonding movement and wettability.

4.2. MELTING

Out of varied furnaces, bottom pouring furnace is suitable for fabrication of metal matrix composites in stir casting route, this sort of furnace contains automatic bottom pouring technique which provides instant pouring of matrix and reinforcement. Automatic bottom pouring is especially utilized in investment casting industry. In stir casting process, the matrix material is melted and maintained a particular temperature for two to 3hours during this furnace. Simultaneously, reinforcements are preheated during a different furnace. After melting of the matrix material, the stirring process has been began to form the vortex.

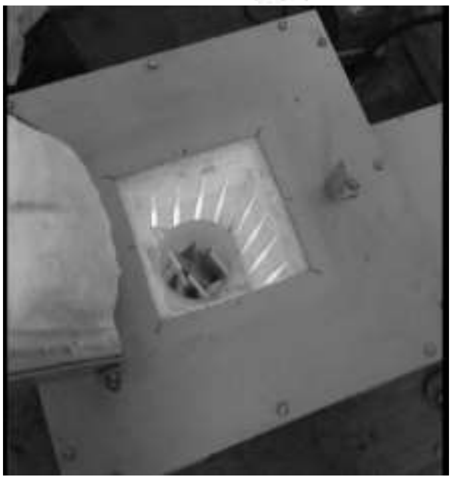


Fig. 1.Melting of Aluminium

4.3. STIRRING PROCESS

In stir casting process, the mechanical stirrer is including the varying speed motor to regulate the speed of the stirrer. Double stage and multi stage stirrer are mainly utilized in chemical industries whereas single stage impeller stirrer is usually used for fabrication of AMCs and HAMCs due flexibility and to avoid excessive vortex flow. Stirring plays an important role over the ultimate microstructure and mechanical properties of the casted composites because it controls the distribution of reinforcements within the matrix.

4.4. BLADE ANGLE IN STIRRING PROCESS

The vortex formed by the stirring on solid-liquid mixing transfers reinforcements particles into the melt from the liquid surface whereas shearing action assist to interrupt the buildup formed by the reinforcement particles and cause uniform distribution. Therefore, selection of an appropriate blade angle is crucial to accumulate good level of axial flow and shearing action. Moreover, stirring time plays a crucial role over the distribution of solid particles and power consumption by the stirring motor.

4.5. STIRRING TIME IN STIRRING PROCESS

Stirring time may be a significant process parameter in stir casting process. Lower stirring time may cause clustering of particle reinforcements and results non-homogeneous distribution of reinforcement particles. Whereas, higher stirring time may cause the deformation of the chrome steel stirrer impeller blade at very high working temperature. The working temperature of some reinforcement with aluminum matrix are very high. This temperature range is 850–950°C, which may deform the stirrer impeller. optimal value of stirring time is essential. has been investigated and suggested 10 min as optimal value of stirring to realize better distribution of reinforcements and uniform value of hardness throughout the composite.

4.6. FEED RATE

Feeder should be designed in such a fashion that it allows continuous flow of particles. High feed rate results particles accumulation within the composite and low federate is difficult to realize thanks to the formation of lumps of small solid particles.
Thus, selection of optimal rate of feeding is crucial. Less than 0.8 g/s is extremely difficult to realize and greater than 1.5 g/s results particle accumulation, hence the optimal rate of feeding is within the range of 0.8–1.5 g/s to avoid the buildup of reinforcements within the composite and achieve homogeneous dispersion of reinforcement particles throughout the composite. Accomplishing homogeneous distribution of particles in the melt and oxidation is the key problem frequently faced in stir casting process, which is controlled by stirring parameters. Therefore, choice of stirring parameters plays major role in stir casting method. Stirring speed, stirring time, impeller blade angle, size of impeller and position of impeller are major parameters, affecting the distribution of the reinforcements in the matrix

Fig 2 .Moulded Alumium Metal Matrix Composite

V TESTING METHODS

5.1 Impact Test

Impact resistance of materials are determined by Izod method of impact test. During Izod test pivot arm is raised to a specific height and then released. During the swing arm hits the specimen to break. The dimensions of a typical specimen for ASTM are 63.5 × 12.7 × 3.2 mm. The utmost common specimen thickness is 3.2 mm, but the width can vary between 3.0 and 12.7 mm.

5.2. MICRO HARDNESS TEST METHOD

Micro hardness tests were performed by alphanumeric display micro hardness tester HVS-1000. The specimens were polished upto the specified standards then held perpendicular to the indenter. The used micro hardness testing machine gives an allowable range of load for testing with a diamond indenter; the resulting indentation was measured and converted to a hardness value. During the test, a continuing load of 0.98 N was maintained.

Fig 3. Micro Hardness Testing

5.3. COMPRESSION TEST METHOD

Compression test is completed within the Universal Testing Machine (UTM). The cylindrical test specimen is mounted on the bottom plate of the UTM. The load is applied on the sample gradually until the sample is compressed until its height decreases by 50%. With increase in load displacement increases to a certain limit then reduces drastically when compressed more. The goal of a compression test is to determine the behavior or response of a material while it experiences a compressive load by measuring Ultimate Tensile Strength.

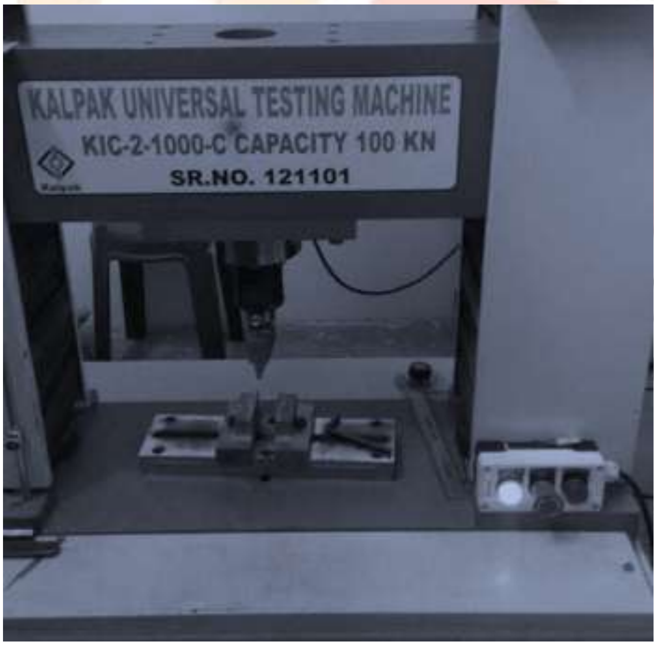


Fig. 4. Universal Testing Machine

5.4. BENDING TEST

Bending test deform the test specimen at the midpoint causing a concave surface or a bend to make without the occurrence of fracture and are usually accomplished to work out the resistance to fracture of that material. Unlike during a flexure test the goal isn't to load the fabric until failure but rather to deform the sample into a selected shape. The test sample is loaded during a way that makes a concave surface at the midpoint with a specified radius of curvature consistent with the quality in reference to which the test is performed. Bending assessments are as popular as tensile test, compression test, and fatigue tests.

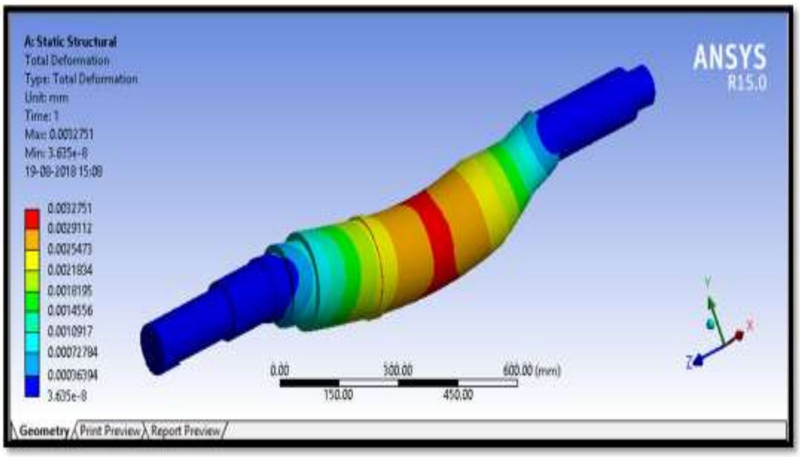
5.5. TENSILE TEST

An UTM is used for testing the Aluminium metal matrix specimens. The specimens were prepared using ASMT standards Constantly increasing speed is applied on the specimen where UTS and percentage elongation is recorded

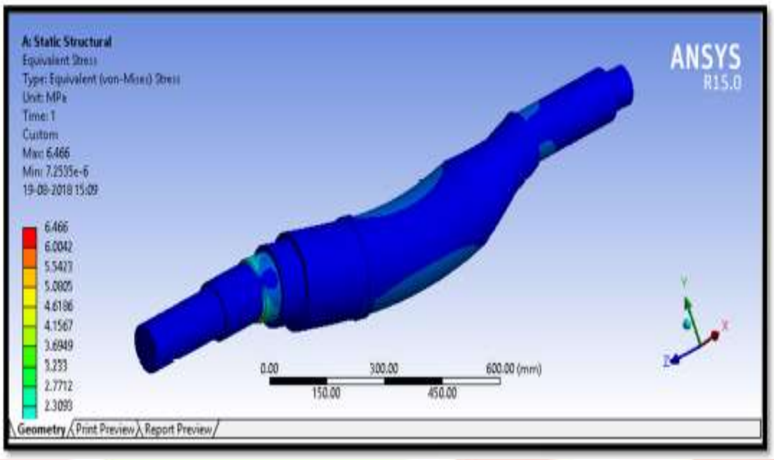
VI.FINDINGS

Static analysis for shaft with materials SAE 1045 and AlSiC (composite).

6.1 Total deformation



6.2 Equivalent stress (Von-Mises)



6.3 Comparison of results for SAE 1045 and AlSiC shaft

SL. NO.	Solution	Material AlSiC	Material SAE 1045	Acceptance Criteria
1.	Total Deformation	0.0063 mm	0.0033 mm	0.11mm
2.	Equivalent Stress	4.99 MPa	6.47 MPa	166MPa

SL. NO.	Solution	Material AlSiC	Material SAE 1045	Acceptance Criteria
1.	Total Deformation	0.139 mm	0.056 mm	0.2 mm
2.	Equivalent Stress	65.33 MPa	65.25 MPa	166MPa

VII.CONCLUSION

It has been observed that the AlSiC composite shaft has the results similar to that of normal SAE 1045 shaft in the case of deformation, stress obtained during the static, modal and torsional analysis, these results are lying within the acceptance limit defined by the IEC and API standard. As per the observation we found these is a difference of 15% from the practical and Ansys results for SAE 1045 shaft. Thus it is assumed that the same will be applicable to AlSiC composite shaft. Thus by using the weight of the SAE 1045 shaft is 216 kg and that of AlSiC shaft is around 77 kg. **There is a weight reduction of 64.4%.** This will help in reduction of weight of the total motor.

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