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Manual Stir Cast Processing Method, Hardness and Compression Characteristics of Quartz Reinforced Al Metal Matrix Composites

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Abstracts

This paper introduces the Composites and their various applicable Reinforcements. The concepts of Matrix material, their various manufacturing techniques to produce materials with high specific strength are introduced. It is difficult to produce hard materials with high load carrying capacity. Thus, the composite materials with varying degree of composition and with modified matrix material to produce materials of unparalleled hardness and high load bearing capability are studied through experimentation. The characteristics of the cast composites with varying degrees of composition are studied by performing hardness test using Rockwell Hardness Machine and Compression Test using Universal Testing Machine (UTM).

Keywords: Composites, Matrix, Reinforcement, Rockwell hardness testing, Universal Testing Machine.

Introduction

All Industrial technology is growing at a very rapid rate and consequently there is an increasing demand and need for new materials. The main emphasis of scientists and metallurgists has been to produce materials that possess great strength and extreme ductility. Great strength offers high load carrying capacity and higher ductility prevents catastrophic failures. However, these two properties are generally incompatible, with most of the metals and their alloys. Considerable research on this direction has resulted in developing a new class of materials called "composite materials". Various metals and their alloys are used as materials for load bearing applications. It is generally accepted that the strength of the alloys comes mainly from the interaction of dislocation among themselves and with the alloying elements.[1] On the other hand, in the composite material, the stiff reinforcing phase is responsible for carrying the load and ductility is due to the tough but less strong matrix. The combination of the matrix and reinforcement thus offers strength as well as ductility.[2,3]However, in composite materials the reinforcement can be aligned in the direction of loading. One of the prime reasons for the use of the metallic composites is the significant advancement that have been made in recent years on the development of the fabrication routes, which are economically attractive and generate materials of high quality. In any composite, there are at least two chemically distinct materials, known as the matrix and the reinforcement. The choice of the processing method depends on the property requirements, cost factor consideration and future applications prospects. In advanced society like ours we all depend on composite materials in some aspect of our lives.

The reinforcement materials can be categorized as:-

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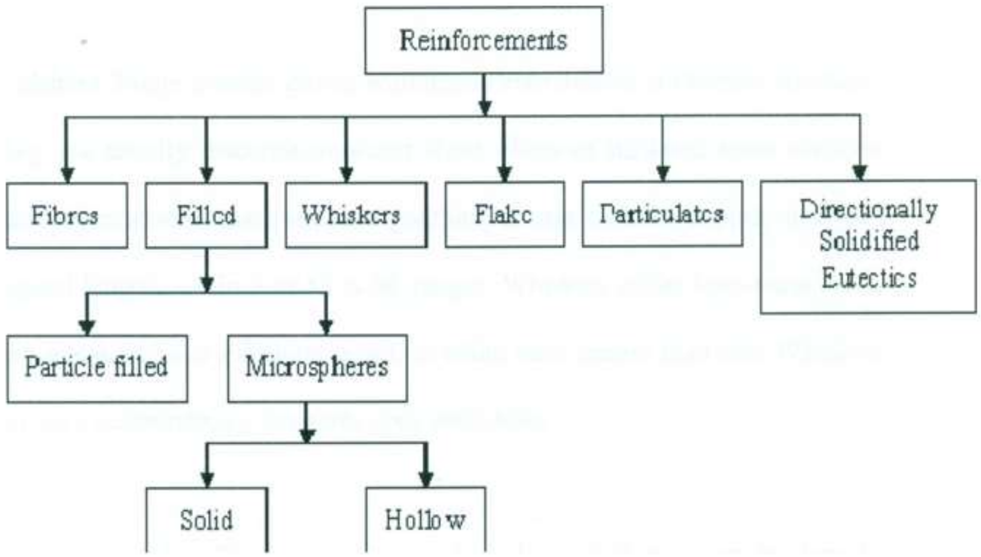

Reinforcing constituents in composites, as the word indicates, provide the strength that makes the composite what it is. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements. A reinforcement that embellishes the matrix strength must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite.

Matrix material

Although it is undoubtedly true that the high strength of composites is largely due to the fibre reinforcement, the importance of matrix material cannot be underestimated as it provides support for the fibres and assists the fibres in carrying the loads. It also provides stability to the composite material.
Matrix Selection -Aluminium and magnesium alloys are regarded as widely used matrices due to low density and high thermal conductivity.

Functions of a matrix: - In a composite material, the matrix material serves the following functions: -

- Holds the fibres together.
- Protects the fibres from environment.Distributes the loads evenly between fibres so that all fibres are subjected to the same amount of strain.
- Enhances transverse properties of a laminate.
- Improves impact and fracture resistance of a component.

Desired properties of a matrix: -
The needs or desired properties of the matrix which are important according to for a composite structure are as follows: -

- Reduced moisture absorption.
- Low coefficient of thermal expansion.
- Reasonable strength, modulus and elongation (elongation should be greater than fibre).
- Must be elastic to transfer load to fibres.
- Low temperature capability (depending on application).
- Excellent chemical resistance (depending on application).

Advantages and Limitations of Composites Materials
1 Advantages of Composites: -
The advantages exhibited by composite materials, which are of significant use in aerospace industry are as follows: -

- Due to greater reliability, there are fewer inspections and structural repairs.
- Directional tailoring capabilities to meet the design requirements. The fibre pattern can be laid in a manner that will tailor the structure to efficiently sustain the applied loads.
- Fibre to fibre redundant load path.
- High resistance to impact damage.
- Like metals, thermoplastics have indefinite shelf life.

2 Limitations of Composites: -

Some of the associated disadvantages of advanced composites are as follows:

- High cost of raw materials and fabrication. Composites are more brittle than wrought metals and thus are more easily damaged.
- Transverse properties may be weak.
- Matrix is weak, therefore, low toughness.
- Repair introduces new problems, for the following reasons.
- Materials require refrigerated transport and storage and have limited shelf life.
- Analysis is difficult.
- Matrix is subject to environmental degradation.

Properties of Aluminium and Quartz

1 Aluminium advantages and properties: -

Physically, chemically and mechanically aluminium is a metal like steel, brass, copper, zinc, lead or titanium. It can be melted, cast, formed and machined much like these metals and it conducts electric current. Strength depends on purity 99.9% pure aluminium has a tensile strength of about 49 MPa which rises to 700 MPa following alloying and suitable heat treatmentas dictated by Lucas and Nesarikar[3,4].

Table 1. Properties and their corresponding values of Aluminium

Properties	Value
Density/Specific Gravity(g/cm^3) at 20^0C	2.70
Melting Point (^{0}C)	660
Specific heat at 100^0C $calg^{-1}K^{-1}$ ($Jkg^{-1}K^{-1}$)	0.2241 (938)
Latent heat of Fusion $calg^{-1}$ ($KJkg^{-1}$)	94.7 (397)
Electrical Conductivity at 20^0C (% of international annealed copper standard)	64.94
Thermal Conductivity $calcm^{-1}sec^{-1}K^{-1}$	0.5
Thermal emmisivity at 100^0F (%)	3.0
Reflectivity for light, Tungsten Filament (%)	90.0

Table 2. Properties of Quartz powder

Properties	Value
Molecular weight	60.08
Melting point K	1986
Boiling point K	2503
Density gm./cm3	2.32
Mohs hardness (at 293K)	7 Modified Mohs
Si%	46.75
O_2%	53.25
Crystal structure	Cubic
Mesh size	230
Size	65 microns

Literature review

Metal matrix composites are the important class of engineering materials widely used in industries. One of the prime reasons for the use of the metallic composites is the significant advancement that have been made in recent years on the development of the fabrication routes, which are economically attractive and generate materials of high quality. In the past, various studies have been carried out on metal matrix composites. SiC, TiC,

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TaC, WC, B4C are the most commonly used particulates to reinforce in the metal or in the alloy matrix or in the matrices like aluminium or iron, while the study of silicon dioxide reinforcement in LM6 alloy is still rare and scarce. The past studies for the hardness test using Brinell Hardness Test have revealed that the increase in the SiC concentration will increase the hardness, impact strength and normalized displacement.[2] But the increase in the hardness alone will render the material very brittle and the load bearing capacity reduces considerably. Hence appropriate manufacturing technique is adopted, and this choice of the processing method depends on the property requirements, cost factor consideration and future applications prospects. Following a series of experiments for the hardness of the material using Rockwell Hardness Testing and the compression testing (load bearing capacity testing) of the materialusing Universal Testing Machine (UTM) on the so manufactured composite a metal matrix composite with appropriate composition is developed such that it is able to withstand high loads and also be hard at the same time.

Manufacturing techniques

Generally two types of fabrication technique for the Metal Matrix Composites are available. They are:

1. Solid state fabrication technique.
2. Liquid state fabrication technique.

Solid state fabrication technique: Among the various methods available to fabricate metal matrix composite using this technique are:

Powder metallurgy: This method is the most preferred method used for the manufacture of metal matrix composites (MMCs)with discontinuous reinforcement, using either whiskers or particulates as reinforcements. In this method, the mixture of powdered matrix material and reinforcement are fed into the mould of required shape. It is then compacted under pressure. This is called cold pressing.

Diffusion Bonding: The diffusion bonding employs the matrix in the solid phase, in the form of sheet or foil. Composite laminates are produced by consolidating alternate layers of precursor wires or fibre mats and metal matrix sheets or foils under temperature and pressure.

Liquid state fabrication technique (or casting): Casting or liquid infiltration is the process in which molten matrix is infiltrated into a stack of continuous fibre reinforcements or discontinuous reinforcements (short fibres and particulates) and is then allowed to solidify between the inter-reinforcement spaces.

Manufacturing of aluminium quartz composite

Due to the availability of limited facilities, manual stir casting method was used for producing Aluminium Quartz metal matrix composite. This process is feasible,because of the aluminium, which has a low melting point and is easily melted in the furnace using coal as fuel.[5-7]

Apparatus used in casting operation:

- 3kg capacity Clay Crucible.
- A flat steel rod for stirring the mixture.
- Weight balance.
- Bowl shaped crucible for Quartz preheating.
- An open hearth set up for melting of Aluminium.

Materials Used:

- Coal used as fuel.
- Aluminium (LM 6 Alloy).
- Quartz powder.

In manufacturing of A1-SiO_2 composite, three specimens of different compositions are prepared.

Table 3. Composition of Specimens

Specimen	Aluminium (gm)	Quartz (gm)
1.	2000	0
2.	1900 (95%)	100 (5%)
3.	1700 (85%)	300 (15%)

Procedure:

- First, required amount of Aluminium pieces and quartz powder is weighed on weighing balance.

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- Further, Crucible is set on open hearth for preheating to remove moisture and other particles from the inner surface.
- 1.7 Kg of Aluminium cubes is fed into the crucible which starts melting as the temperature of open hearth goes to around 853K.
- Meanwhile, Quartz is preheated to 473K in a bowl crucible in the same hearth. This activity is carried out in order to remove moisture from Quartz powder.
- As the temperature of hearth reaches to 923K, i.e. the melting point of aluminium, Al cubes in the crucible will meltdown.
- Further, crucible is removed from the hearth and liquid Al in the crucible is air cooled by continuous stirring by a steel rod until it reaches to semi-solid state (viscous phase at temp. near 873K).
- Then 300gm of preheated (473K) Quartz powder is poured slowly while stirring into the crucible containing semi-solid Aluminium.
- Manual stirring is continued for 5 to 6 minutes at constant temperature of 873K and is air cooled.

Figure 1.Crucible used in Melting of Aluminium.

Application of the A1-SiO_2 composites
Since the electrical and thermal conductivity of Aluminium is high, the metal matrix composites has vast application in electrical and electronic industries.[8]Due to the improved hardness, Al composites are employed as a substitute over Pure Aluminium in automobile industries.[9]

Hardness Test: Hardness is the property exhibited by all materials. Hardness is defined in different ways, depending upon the various hardness test used. Some of these definitions are:

- Resistance to permanent indentation- under static or dynamic loads – indentation hardness.
- Energy absorption under impact load – Rebound Hardness.
- Resistance to scratching – scratching hardness.
- Resistance to abrasion – wear hardness.
- Resistance to cutting or drilling – machinability.

Testing of the Cast Composites for Hardness and Compression Strength (Load Bearing Capacity)

Hardness test

Rockwell hardness machine:- When a machine is intended, it opposes indentation. The degree of resistance offered by the metal is commensurate with its hardness. If the hardness is more, the resistance to indentation is more and vice versa. Thus, one will have small indentation with hard metals and larger indentation with soft metals. Based on this phenomenon one can see that the depth of indentation is also inversely proportional to the material hardness. This technique can be utilized as the means of measuring the hardness as stated by Shen [2]. Rockwell hardness tester is developed with the depth of penetration as the criterion for the hardness of the metal.

Machine Description: - The machine consists of anvil which can be changed depending on the shape of the specimen under test. A loading lever is situated at the right hand side bottom portion of the machine. The machine is a direct reading type. The dial consists of two pointers. The small pointer which is situated in top left quarter of the dial proper indicates the application of minor load of 10kgf. The dial has two sets of markings, one red and the other black. The outer set is marked in the black is C scale and the inner red is B scale. B scale is used for steel ball indentor and the C scale is used for diamond one. A total load of 100 kg and 150 kg are used for B and C scale respectively.

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Figure 2. Rockwell Hardness Machine

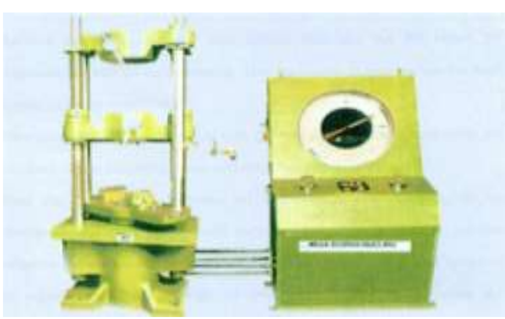
Procedure:

- First, the surface of the specimen composite is cleaned by rubbing it with sand paper in order to remove dust/oil from the surface.
- In this hardness test, steel ball indentor is employed.
- Further, pro weights are attached to the suspension level.
- The hand wheel of the machine is rotated clockwise in order to raise the table until the contact is made with penetrator.
- Now, major load of 90kgf is applied by pushing back the lever on the right hand side of the machine to its full extent.
- The major load is removed by raising the hand lever when the reading of the indentor becomes steady.
- The hardness number is noted down from the appropriate scale.

Compression test

Universal Testing Machine Specifications: -

Ram Diameter: - 222.2mm.
Maximum load value: - 2KN.



Observations:-

Figure 3. Universal Testing Machine (UTM)

Procedure:

- All the connections are checked and confirmed and main switches are switched on.
- The release valve and the control valve mounted on the control unit are closed.
- The middle crosshead of the loading unit is moved up and down with the help of mechanical motors, there by the space from the upper crosshead and middle crosshead decreases or increases.
- Now the machine is switched on and the control valve is opened gradually.
- As soon as the control valve is opened the changes on load dial/display along with displacement dial/display is observed.
- The value of load will increase for some time and then remain stationary but the values for displacement will go on increasing. This load value is nothing but the dead weight of lower crosshead.
- Now, the load reading is made zero with the help of tare switch. The machine is shut down. The control valve is closed and the release valve is opened.
- The backflow of hydraulic oil is noted and the slow lowering of the crosshead is observed.
- A Quartz composite specimen is inserted between middle and lower crosshead. After selecting the suitable range on load dial gauge the release valve is closed and the control valve is gradually opened.
- The reading of load at different instants are noted.
- The load is applied till failure of the specimen takes place, this is the maximum load or failure load generally denoted by P.
- The machine is switched off. The control valve is closed and the release valve is opened.

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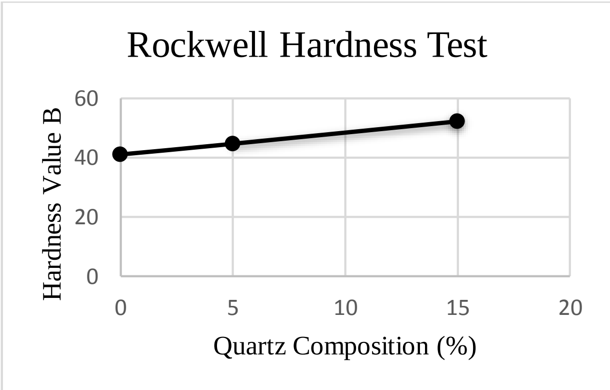
Table 4. Observation Table obtained after performing the Hardness Test

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Pure Aluminium	B 40	B 43	B 40	B 43	B 39	B 41
95% Al + 5% Quartz	B 46	B 39	B 48	B 46	B 44	B 45
85% Al + 15% Quartz	B 51	B 57	B 49	B 52	B 52	B 52

Figure 4.Specimen with 5% Quartz composition in Aluminium Quartz composite.

The variation of the Hardness Value B with the percentage variation of the Quartz Composition is shown in the graph below by selecting appropriate scale.



Graph 1. Quartz Composition (%) V/s Hardness Value, B

Observations from the compression test performed on the Universal Testing Machine (UTM) were tabulated as follows:

Table 5. Observation Table obtained after performing the Compression Test.

	Diameter D = 2r (mm)	Area (mm^2)	Compression load, F (KN)	Ultimate Strength αu = F/A (N/mm^2)
Specimen 1 Pure Aluminium	65	3318	574	173
Specimen 2 Al – 95%, SiO_2 – 5%	80	5026	748	148.8
Specimen 3 Al – 85%, SiO_2 – 15%	90	6361	900	141.5

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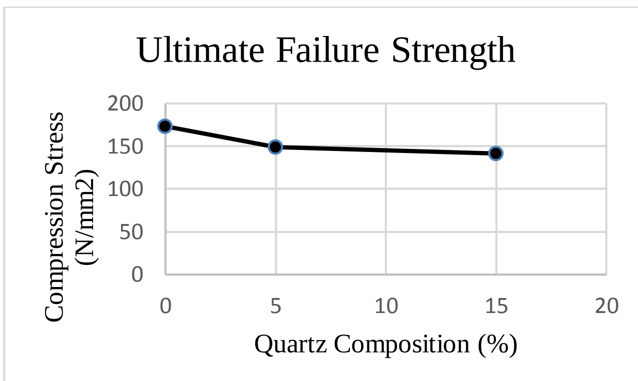
Figure 5.Test specimens after Compression Test

The variation of the compression stress (in N/mm^2) with the percentage variation of the Quartz Composition is shown in the graph below by selecting appropriate scale.



Graph 2. Quartz Composition (%) V/s Compression Stress (N/mm^2)

Discussions

The hardness of the composite increases with the increase in weight percentage of the reinforcement. Since quartz is harder material, when dispersed in the matrix the combined hardness increases.[10] The hardness increase is also due to the increase in nucleation sites (crystal imperfections) for the mobility of dislocation.[11] So strain hardening index increases with the addition of harder reinforcements. The compression test also supports the argument that compression strength of the metal increases with the increase in weight percentage of reinforcement also confirmed by Gnjidiet al.[12-14]. Toughness is related to the increase in strength with increase in area under the stress – strain curvealso in accordance with Poole [15]. So there is increase in strength and toughness of the composite with the increase in weight percentage of reinforcement. [16-18]

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Conclusion

1. Semisolid processing technique is better method to manufacture the composite material when there is much variation in the densities of the matrix and reinforcement material.
2. Stir casting technique is very useful for casting low melting point matrix with high melting point reinforcement.
3. Porosity and other related casting defects are observed due to some uncontrolled parameters.
4. There is much improvement in hardness of the composite specimens as the weight percentage of particulate increases.
5. From the graph of the compression test, depicting the Ultimate Failure Strength, it can be concluded that with the increase in the weight percentage of Quartz in

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Aluminium Quartz composition, the compression load bearing capacity also increases.

6. From the combined tests for Hardness of the material using Rockwell Hardness Test and load bearing capacity (Compression Test) using Universal Testing Machine (UTM), the appropriate composition of the Quartz in Aluminium Quartz composite is determined, which is hard as well as, has high load bearing capabilities.

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