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AN EXPERIMENTAL INVESTIGATION ON SQUEEZE CAST AL-SIC PARTICULATE

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ABSTRACT

Al — Sic squeeze cast composites casting are prepared by using a "Vortex liquid metallurgy" technique and their mechanical properties like ultimate tensile strength, 0.2% offset yield strength, 0.2% elongation, wear rate and hardness values are evaluated. In each case, the articulate mixture, Al — Sic containing 15% Sic is stirred into well super-heated Al melt. The amount of particulate mixture addition is varied from 0 to 8 weight% in an interval of 2 weight%. The stirred slurry is squeezed in the pressure range of 20 to 80 MPa, by an increment of 20 Mpa in each stage. A 40-tonne universal testing machine is used to squeeze the composites in between the hot die steel punch and die.

In the present work, to validate the experimental set-up sample castings were made using LM6 Aluminium alloy. These sample castings were made at different preheating temperatures of the die and at different loading conditions.

The sample castings made were subjected to mechanical properties studies and metallurgical properties studies. Under the mechanical properties, UTS, hardness and 0.2% yield strength were measured under metallurgical properties, the microstructure of the sample castings were analysed.

Keywords: Squeeze Casting, Powder Metallurgy Process, Compocasting, Rapid Solidification Process, Ultimate Tensile Strength

1. INTRODUCTION

There is considerable interest In replacing cast Iron and stool components because of their undesired properties Re loss corrosion resistance, heavy weight and bad surface qualities. Normally these materials are replaced by the low-cost Aluminium particularly in the field of automotive components such as brake discs, engine cylinder blocks, pistons, aircraft parts and in structural components. The major advantages of the Aluminium are its

- Light weight,
- Best corrosion resistance,

- Good thermal conductivity
- Reflective surface.

In automobiles the vehicle performance and efficiency also improve because of the lightweight components made by Aluminium. The strength of the Aluminium is further increased by adding some of the alloying elements or by adding ceramic materials as composite materials. Normally these ceramics are in the form of particulate. Ceramics are mainly used for high temperature properties like withstanding high temperature, tensile strength, hardness, good heat and wear resistance, reduced friction, and insulative properties. The main application of these composites is in the jet engine arts and automobile engine parts like engine valves, value valve seat inserts, piston pins, and bearings etc.

Sometimes more strength is required in a particular direction or particular location. This is obtained by infiltrate suitable coated ceramic perform placed in that location. Thus, selective reinforcement of the component is performed, which results in improved mechanical properties in that location. For this purpose, copper inserts of suitable diameters placed in the specimens and casted.

From the above, the potential of metal matrix composites such as high specific stiffness and high temperature performance has been known for many applications, particularly, these Aluminium — Alumina composites for higher temperature mechanical properties. But high manufacturing cost and fabrication difficulties are the major reasons which limit the application of composites.

The following are the methods to be used for the manufacturing of composites.

- Powder metallurgy processing.
- Compocasting.
- Squeeze casting

Among the three, squeeze casting is the cost-effective method, as it offers.

- Good suitability for mass production and
- A relatively simple process for manufacturing near net shaped components.

Squeeze casting sometimes known as liquid forging process is hybrid in nature and enjoys the advantages of both casting and forging in a single step by which near net shaped components can be casted. Squeeze casting process was introduced in the united states in 1967 by the Group Technology Centre. They produced prototype car wheels first, then extended for engine piston manufacturing. There are also some investigations carried out in Russia, Germany, and Japan. In India, this process though not very popular, is slowly picking up moment .

In recent years, squeeze casting has found production applications in the United States, UK and Japan for Aluminium alloys and metal — matrix composites. In 1983 Toyota used squeeze cast fibre reinforced aluminum pistons for high-speed diesel engines and car wheels. The squeeze casting Technique is still in the experimental stage in India. With rapid expansion of automotive and aerospace sectors, the demand for superior engineering components is expected to increase in course of time and squeeze casting technology has the potential and it will play an important role to improve the quality of engineering products. In squeeze casting, metered amount of liquid metal is poured into the cavity of a preheated die (metallic die). Immediately metal is pressed with high pressure (20Mpa — 80Mpa) and pressure is maintained while metal solidified. The pressure is released after completion of solidification.

Since the solidification of metal takes place under high pressure, the castings are free from pores, blow holes and other discontinuities and have refined grain structure. Shrinkage porosity is prevented by feeding of molten metal to the solidification interface from within the part itself. There is no need for gates and risers, also the yielding of the process be 97% for non-ferrous metals.

Squeeze casting components can be further processed and subjected to common secondary operations like heat treatment, welding machining and surface finishing. Squeeze casting depends upon satisfactory key process parameters like melt quality, casting temperature, die temperature, delay time, pressure level and duration of application of pressure.

During solidification, due to high pressure, rapid extraction of heat takes place from the molten metal through metallic dies, which results in fine grain structure and improvements in the mechanical properties of the component. In the present work, an attempt will be made to make Al Sic particulate using square casting process. The castings obtained with this will be analyzed for its mechanical properties like UTS, Hardness, % elongation, ductility.

In any casting process, the structure of the castings is largely depending on their cooling characteristics during solidification. In this work, the heat transfer analysis during solidification will also be performed to know the cooling characteristics of Al — Sic particulate.

1.1. Scope of the Research work

It is observed from the literature survey that metal matrix composites (Metallic and Non-metallic) particle and fibre reinforced are designed for specific end application like aerospace and automotive components. They also exhibit high strength at elevated temperatures. There are two methods to produce articulate composite.

- Powder metallurgy
- Vortex liquid metallurgy and squeeze casting.

The former is a cost consuming and a difficult process for large components. Therefore, this vortex liquid metallurgy and squeeze casting technique is the best method for MMC preparation. The method gives uniform dispersion of particulate in the base matrix. Squeeze casting reduces the shrinkage porosity and also increases the gas solubility, so that the pores be very less. It also increases the grain refinement, and the mechanical properties of the component.

In this research work it is proposed particulate composite by vortex liquid metallurgy method and cast the composite by squeeze casting method by varying the squeeze pressure and the amount of particulate added. A copper rod is also inserted into the die before casting. The following measurements are taken, and they are compared

- Brinell Hardness Number
- Wear Resistance
- Ultimate Tensile Strength
- 0.2% Offset Yield Strength
- % Microstructure
- Microstructure

These results are also compared with gravity chill cast.

2. REVIEW OF LITERATURE

Review of literature reveals that a few investigations have been carried out in the past in squeeze casting using different non-ferrous alloys.

[1] Prof. S.Seshan published a paper on "SQUEEZE CASTING PRESENT STATUS AND FUTURE TRENDS". In this paper, various process parameters such as effect of pressure on solidification are discussed. A variety of squeeze cast using Copper, Aluminium, Zino alloys are tested. From that, whatever be the alloy squeeze casting reports best properties compare to other casting methods including extrusion process. Properties of Aluminium bronze are also tested at high temperatures. Finally, he reported that, squeeze casting is the most economical route over others for the production of composite (MMC) materials. This is from "Indian foundry journal", June 1996.

[2] "SQUEEZE CASTING OF ALUMINIUM AND ITS ALLOYS", Kunal Basu et al noticed that, application of pressure in the case of squeeze casting increases solubility of gas in the metal, there by reduced gas related porosity. And also, fine equiaxed grain structure is formed due to the synergetic action of under cooling below the equilibrium solidification temperature and a rapid rate of heat extraction, which causes extensive nucleation. They also concluded the following:

- This process can produce sound casting with good surface finish closely mirroring that of inner surface.
- The temperature of molten metal at the time of pressure application should just above the liquids.
- Uniform as well as slightly increased hardness value across the cross section of squeeze cast sample may be useful to verify, whether sample is properly squeezed or not.

[3] Dr.S.V.Sambasivam and A.Syed Abu Thaheer of G.C.T., Coimbatore have published a paper on "SQUEEZE CASTING — INFLUENCE OF SQUEEZE PRESSURE ON DAS AND OTHER RELATED PROPERTIES". In their paper, they discussed the influence of squeeze pressured on mechanical properties and influence of DAS on mechanical properties. They formed some (mathematical) relation for B.H.N, U.T.S, %E and F.S. (Fatigue Strength) in terms of DAS. Form that, the following points are observed.

- DAS which is the distance between the adjoining arms of dendrites DAS decreases with increase in squeeze pressure.
- Decrease in DAS improves mechanical properties.
- Hardness, UTS, and Ductility has increased with increase in squeeze pressure.

[4] Mr.Y.Nishida and H.Mastsubara in their paper "EFFECT OF PPRESSURE ON HEAT TRANSFER AT THE METAL MOULD CASTING INTERFACE" have told that because of pressure, the ideal contact takes place between the molten metal and the die. Thy noticed that because of pressure,

- A sharp change is encountered in the heat transfer,
- Shifting of melting point results under high pressure,
- Thermal resistance decreases under load.

[5] S.Chatterjee & A.A.Das discussed the "EFFECTS OF RESSURE ON THE SOLIDIFICATION OF SOME COMMERCIAL ALUMINIUM — BASE CASTING ALLOYS". In that paper, they mentioned that the solubility of gas increases because of the pressure tightness. They developed a two-stage gravity die casting process. In the first stage the metal is transferred to the die and in the second stage, a high pressure is applied subsequently. They encountered that, this method improves the soundness and dimensional accuracy of the casting. It is observed that because of pressure, the metal is pressed tightly against the mould walls and the air gap is almost eliminated. The liquids

temperature of the melt increases. From the two points, as steep temperature gradient exists, which leads to increase in rate of heat abstraction and grain refinement. Applied pressure is expected to improve wetting of the substrate by the liquid metal by affecting the overall force balance existing at the interfaces.

[6] In the paper "HIGH QUALITY SQUEEZE CASTING OF MONOLITHIC AND OF REINFORCED ALUMINIUM ALLOYS", by G.A.Chadwicth, he mentioned, Squeeze casting is the process offers lower cost route for the production of metal matrix composites, compare to powder metallurgy process. From this paper, it is observed that the compacting of metal powders in hot press is very difficult and it also leads to more erosion of the dies.

[7] From the experiment conducted by D.L.ZHANG and et al. Squeeze casting is the more advantageous compared with conventional casting routes such as sand and investment casting for the preparation of metal matrix composites. Because the fluidity of the MMC is low compared to monolithic aluminium alloys. Low fluidity is enough for squeeze casting technique because metal does not flow into the runners and ingates, in other castings like sand castings.

[8] In the article, "CHARACTERISTICS OF ALUMINIUM BASE COMPOSITE MATERIALS DISERSED WITH A1203 PARTICLES", by Hyuk-Moo kwon and et al, an experimental method is established. In that method, the alumina particles are mixed with the base matrix in between the liquidus and solidus temperature. But in practical, controlling the melt temperature very close to a particular temperature is very difficult at the time of mixing. In this paper, it is concluded that the Magnesium has a much more attractive force with oxygen than Aluminium has. It reduces the surface energy and improves the wettability. The following are the conclusion gained:

- Mg concentration around alumina particle is high owing to interfacial reaction between alumina and metal matrix.
- An increase in the alumina particles decreases thermal expansion co-efficient and thermal conductivity of the composite.

3. SQUEEZE CASTING PROCESS- AN OVERVIEW

Squeeze casting is also known as liquid pressing, is the displacement of an accurately metered dose of liquid aluminium alloy in a closable, preheated die where the punch continues to exert a load on the metal throughout solidification.

3.1. Process

This can be done in three stages

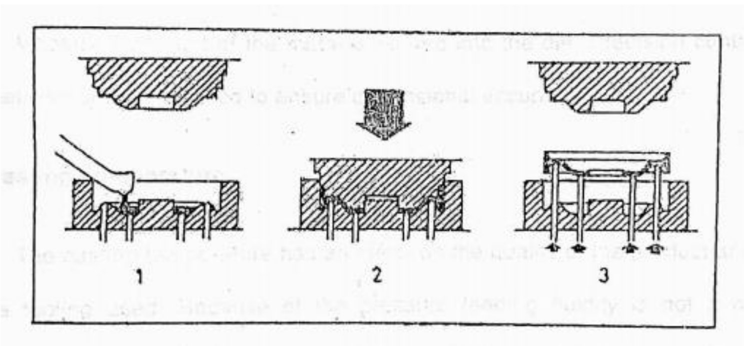

Figure 1 Schematic Representation of the Squeeze Form Process

- Delivery of the dose (Melt) into the open preheated, lubricated lower die.
- Rapid descent of punch into the metal pool with heavy pressure (20-80 Mpa) until solidification completes.
- Component ejection and die maintenance.

3.2. Process Variables

There are number of variables that are generally controlled for the soundness and quality of the casting. The variable ranges discussed in the following sections vary with the alloy system and part geometry being squeeze cast.

3.2.1. Melt Volume

Measured amount of the metal is poured into the die. Precision control of the metal volume is required to ensure dimensional accuracy.

3.2.2. Casting Temperature

The casting temperature has an effect on the quality of the product and life of the tooling used. Because of the pressure feeding fluidity is not a major requirement and hence lower temperatures can be used, compare to other process. Too low pouring temperature will cause insufficient die filling and premature solidification. Die life is adversely affected by high temperatures.

3.2.3. Tools Temperature

Tooling temperatures ranging from 200°C to 350°C are normally used. The lower range is more suitable for thick section casting. The punch temperature is kept 15°C to 30°C 'below the low die temperature to maintain sufficient clearance between them for adequate venting. Higher die temperature causes welding to occur between the casting and die.

3.2.4. Time Delay

Time delay is the duration between the actual pouring of the metal and the instant punch contacts molten pool and starts the pressurization of thin webs that are incorporated into the die cavity. Time delay is determined by the pouring temperature and the component shape. Delay times generally differ but range from a few seconds to one minute for large aluminium components.

3.2.5. Pressure Level

As the alloys differ in their characteristics, the squeeze pressures range for 20 to 80 MN/mm2. These are the minimum values of pressure to obtain sound castings. High pressures may improve mechanical properties but reduce die life.

3.2.6. Pressure Duration

This is controlled according to the alloy type and heat transfer conditions. Till solidification is complete, pressure is to be maintained but slightly longer times may prevent hot tearing. A thumb rule is to allow 1 sec for 1 mm thickness of the component.

3.2.7. Ram Speed

High velocity of the impact between punch and the molten is can cause flash at joint. Peak pressures occurring in a transient can cause premature solidification and it can prevent further compaction of the component.

3.3. Materials

In this composite, the base matrix used is pure aluminium ie., (LM6).

Silicon Carbide

Silicon Carbide is one of the acid refractories which is used as particulate in this investigation.

Properties of Refractory Materials

- They should be heat corrosion and abrasion resistant.
- They should possess high fusion temperature.
- They should possess low thermal co-efficient of expansion.
- They should not have chemical affinity with the molten metal to which they may have contact.
- They should be able to withstand high temperatures and pressures.

4. WORKING METHODOLOGY

4.1. Experimental Setup

The fundamental information' of the squeeze casting is that solidification takes place under high pressure. For the application of pressure, a 40 Tonne Universal Testing Machine is used. The complete experimental setup is shown in the figure 1. In this arrangement the die (H i — Hot die steel material) is bolted to the base plate and both are firmly fitted on the hydraulic table of the UTM. A ceramic electrical heater of 450°C (max) is used to preheat the die. It has a controller and thermo couple arrangements. From this arrangement, the die temperature can be controlled accurately. A pouring plate is also fitted over the base plate for easy pouring. The die dimensions and their draft allowances are given in the figure 2. The punch is bolted with the middle cross head of the UTM.

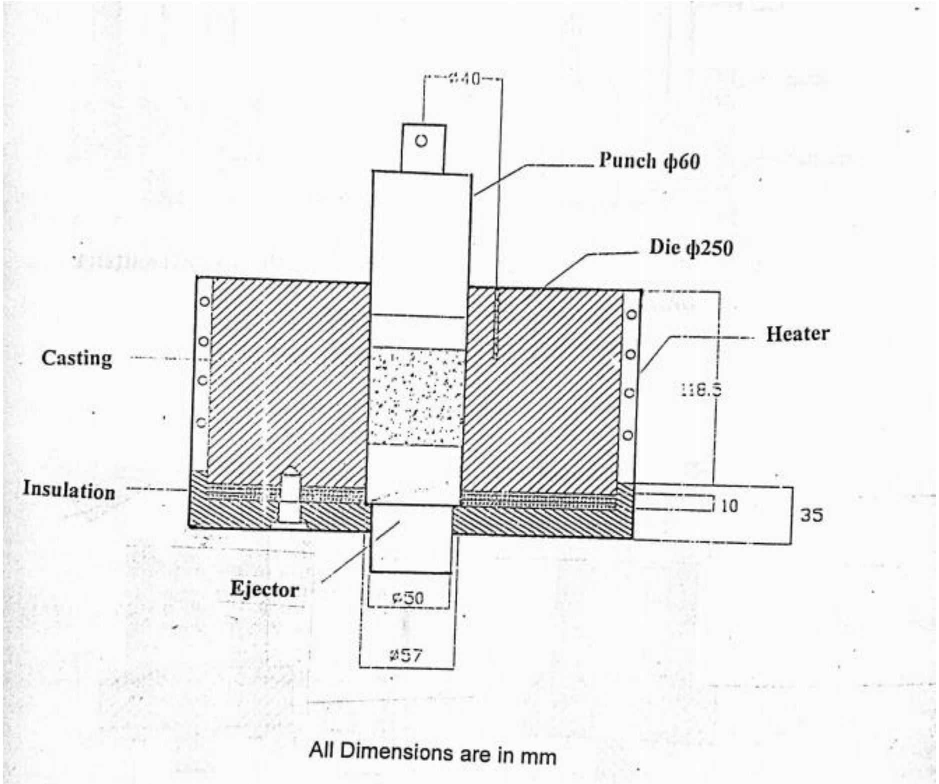

Figure 2 Experimental Setup (Assembled View)

Two furnaces are used for melting the metal and for heating the ceramic particles. An electric resistance muffle furnace (1200°C max) is used for ceramic particulate, (Al — sic) heating and a coke fired crucible furnace for melting the aluminium. The coke fired crucible; furnace is a special custom built. A stirrer motor assembly is also fitted to the crucible furnace for the purpose of mixing the ceramic articulates with the melt. The temperature of the melt is measured by a Cromel-Alumel (range 1200°C) thermocouple.

4.2. Experimental Procedure

From the literature survey, the "Vortex liquid metallurgy route" is the very easiest and more efficient method for the preparation of Al-sic particulate composites. Here also the same method is followed for the preparation of the composite. In this method a vortex is created in the liquid metal using the stirrer motor arrangement and the ceramic particles are added gradually to the melt.

4.2.1. Preparation of melt

Aluminium ingot (LM6) is cut into small pieces. A weighed amount of metal is placed inside a refractory crucible and the heating (melting) is carried out in the crucible furnace. The crucible is closed with a refractory plate to prevent oxidation. Temperature of the melt is closely monitored by using the Cromet — Alumel thermocouple. The temperature of the melt be controlled in between 740-820°C. if the temperature is below 740°C, it leads to rejection of the articulates and it is more than 820°C means more erosion of the stirrer blades. After the melt is heated around 800°C it is degassed by using hexachloroethane.

4.2.2. Preparation of ceramic particulates

The ceramic particulates (Al — sic) are taken in the ratio of 85 : 15 this mixture is placed in a plastic container and mixed for a period of 30 min in a mechanical mixture. From this mixture, calculated amount of particulate is taken in a graphite crucible and heated to 900°C for a period of 1 hour, in the electric resistance muffle furnace. This will lead to dihydroxylation and increase surface energy.

4.2.3. Preparation and squeezing of Composite

After the preparation of the melt and the powder mixture, a vortex is created in the melt by using the stirrer motor assembly. The speed of the motor can be adjusted according to the requirements. Now the prepared powder mixture is gradually added along the walls of the vortex. The stirring of the melt is continued for 2 min. after the addition of the particulate to incorporate the powder mixture fully. During the time, the temperature is maintained in between 740- 820°C. The pouring plate is also heated to a certain degree of temperature and placed on the base plate. The metered quantity of stirred slurry is poured into the cavity. Then the pressure is applied through the punch and the slurry is squeezed for 60 sec. After the completion of the squeeze, the casting is ejected out using the ejector. Squeezed cylindrical casting of 60 mm diameter and 60 mm long is obtained. The location of test positions is shown in the figure 3.

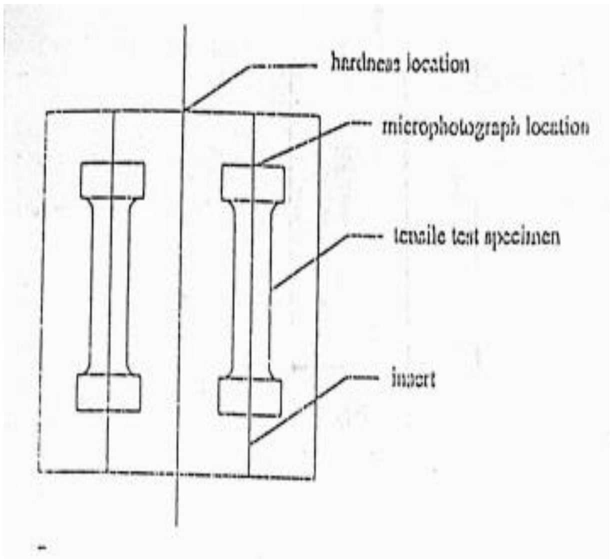

Figure 3 Location of Test Points

4.3. Testing

After the removal of casting from the die, the surface hardness is measured (Brinell hardness) in the hardness tester according to the standard procedure. Then the casting is cut into four equal pieces. Three tensile specimen and one wear test specimen are prepared from these four pieces. The dimensions of the specimens are shown in the figures 4 and 5 given below.

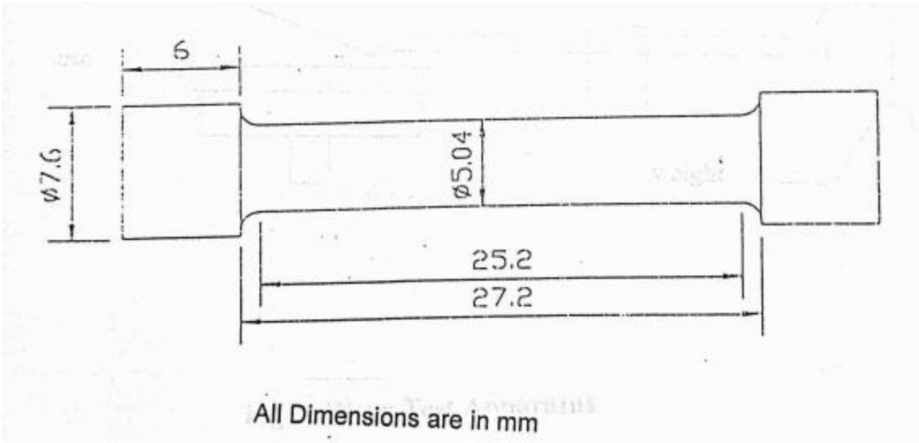

Figure 4 Tensile Test Specimen

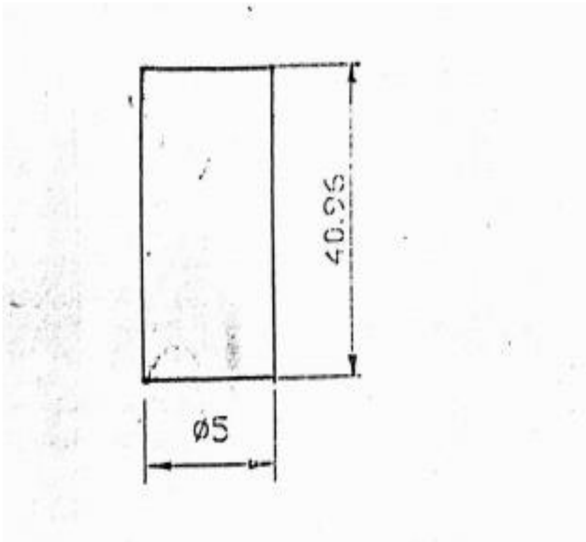

Figure 5 Wear Test Specimen

Tensile test is conducted by using MONSANTO Tensometer at VLB Janakiammal Engineering College, Coimbatore at various temperature (Ambient, 100cC & 200°C) conditions. The [lighter temperatures (100°C and 200°C) are obtained by keeping a tubular resistance furnace around the tensile specimen. A socking period of 10 minute is allowed for getting a uniform temperature throughout the specimen. From this test, the ultimate tensile strength, 0.2% offset yield strength and % of elongation values are calculated and are tabulated.

Wear test is conducted using the PIN-ON DISC type wear testing machine at VLB Janakiammal Engineering College, Coimbatore whose schematic diagram is shown in the figure 6 given below.

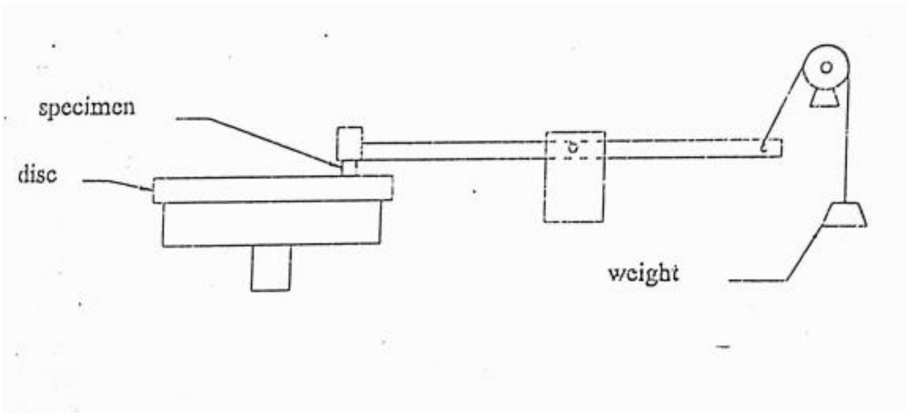

Figure 6 Wear Test Apparatus

5. RESULTS AND DISCUSSION

Squeeze casting is a process in which solidification takes place under pressure. Results in a densified and grain-refined structure. Such a component possesses minimum porosity level. Both the above points form a much-improved mechanical property level. Along with this, the composite material is prepared by taking Al and Sic, prepared by squeeze casting technique is tested under elevated temperatures. The obtained values are shown in the Table. By varying the amount of particulate, their mechanical behaviours are checked for different squeeze pressures. In this investigation, the best results are obtained.

In the present work, to validate the experimental set-up sample castings were made using LM6 Aluminium alloy. These sample castings were made at different preheating temperatures of the die and at different loading conditions. The sample castings made were subjected to mechanical properties studies and metallurgical properties studies. Under the mechanical properties, UTS, hardness and 0.2% yield strength were measured under metallurgical properties, the microstructure of the sample castings were analysed.

5.1. Microstructure Observation

Microstructure is the characteristic appearance and physical arrangement of metal, the same is observe with Metallurgical microscope. In this observation a VERSAMET — 3 microscopes are used. A sample of the microstructure for the casting obtained without the application of the pressure is given in the figure. Similarly, the microstructure of the casting obtained with the application of pressure is stated. From the microstructure, it reveals that when the pressure is applied the grains become finer in size, thus improves the mechanical properties.

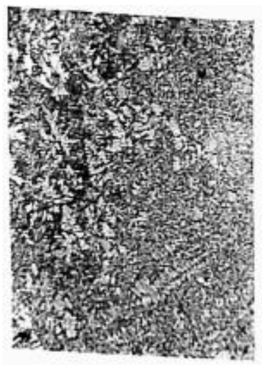

Figure 7 Pure Aluminium (LM6) alloy without Squeeze Pressure

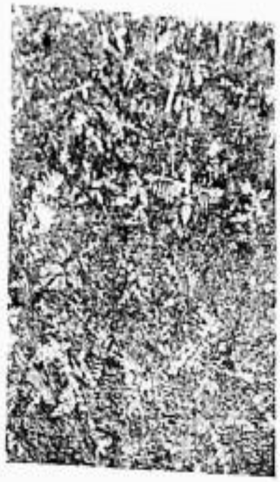

Figure 8 Pure Aluminium (LM6) alloy with Squeeze Pressure

5.2. Ultimate Tensile Strength

Ultimate tensile strength refers to the force needed to fracture the material.

- The results of this study shown in the tables and graphs. Ultimate tensile strength increases as the squeeze pressure increases.
- Ultimate tensile strength decreases as a die Temperature increases. From the graph as shown in fig respectively visualizes ultimate tensile strength increases as the pressure increases.

5.3. 0.2% OFFSET YIELD STRENGTH

Yield strength of a material represents the stress below which the deformation is almost entirely elastic. This is obtained from stress-strain curve. The 0.2% offset yield strength is shown in the Figures. The graphs are drawn by taking test temperature, in the x-axis and 0.2% yield strength in the y-axis. From the graph as shown in fig respectively it is observed.

- Maximum of 0.2% offset yield strength is obtained at 80 Mpa pressure.
- Increase in squeeze pressure increases the 0.2% offset yield strength.
- Increase in die temperature decreases the 0.2% offset yield strength.

5.4. Percentage of Elongation

The data for % of elongation is drawn in graphs and are shown in the Fig 11. The test temperature is taken in x-axis and % of elongation in y-axis. From the fig it is observed

- Increase of test temperature increases the % of elongation.
- Increase of squeeze pressure also increases the % of elongation.

5.5. Hardness Test

Hardness may be defined as resistance of metal to plastic deformation by identification. In this experiment, the Brinell Hardness test is conducted according to the standard procedure. The procedure is given in the appendix. The obtained results are plotted in the Fig 12. The graph shows the variation of hardness with squeeze pressure for various amount of addition. From the graph, it is observed that.

- The Hardness increases, with increase squeeze pressures.
- The hardness decreases, with the increase of the die temperatures

5.6. Heat Transfer study

From the tables, which are enclosed, it is observed that as the pressure increase the mechanical properties also increases. This means that by application of pressure the solidification time decreases. To validate his heat transfer study has been carried out.

The carry out this study six thermocouples have been placed inside and outside the die to measure the temperature at different points during solidification. A data scanner will be used to record the temperatures. The temperature data obtained will be used for plotting time vs temperature curve.

From the curve solidification time will be calculated and heat transfer will be compared with other particulates and other process. A sample of such temperature data obtained is shown in table. From the values obtained, the thermal conductivity and thermal diffusivity will be calculated as described.

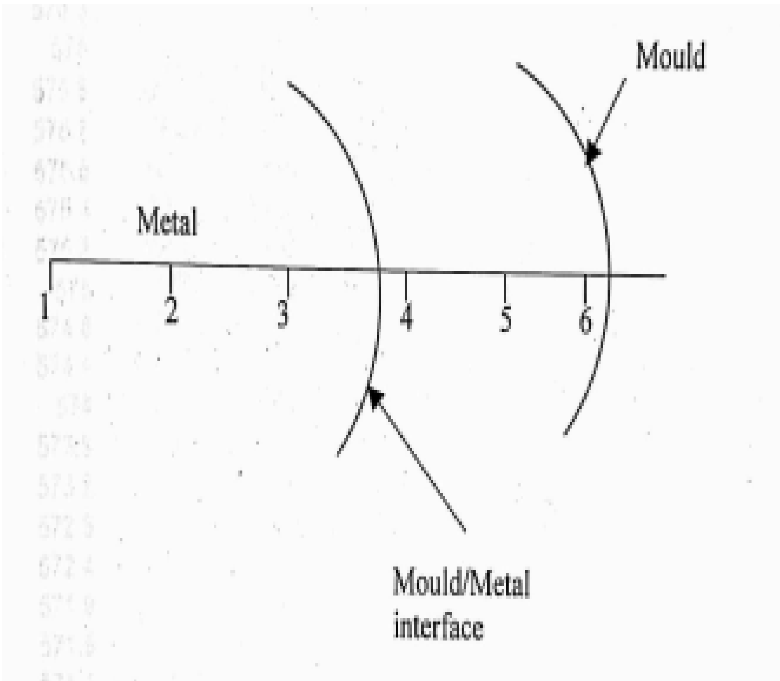

Figure 9 Thermocouple Locations in Heat Transfer study

Die Temperature in °C	Squeeze pressure In Tonnes	Ultimate Tensile Strength N/mm^2	Brinell Hardness Number	.2%Offset Yield Strength N/mm^2	%Of Elongation on 35x10-3m Gauge length
150	Nil	46.905	25	19.7001	27.42
	10	61.7123	56	25.59	40.857
	15	64.059	65	28.18	43.5714
	20	68.038	73	31.29	53.65
250	Nil	42.325	22	17.6	22.2
	10	59.6433	45	24.05	31.428
	15	60.7176	54	26.71	32.714
	20	63.66	65	29.28	37.85714
350	Nil	38.153	20	15.8	13.14
	10	55.704	34	23.39	31.4571
	15	59.582	47	26.34	34.1428

Table 1 Test Results on Mechanical properties of Squeeze Cast Al-SIC Particulate

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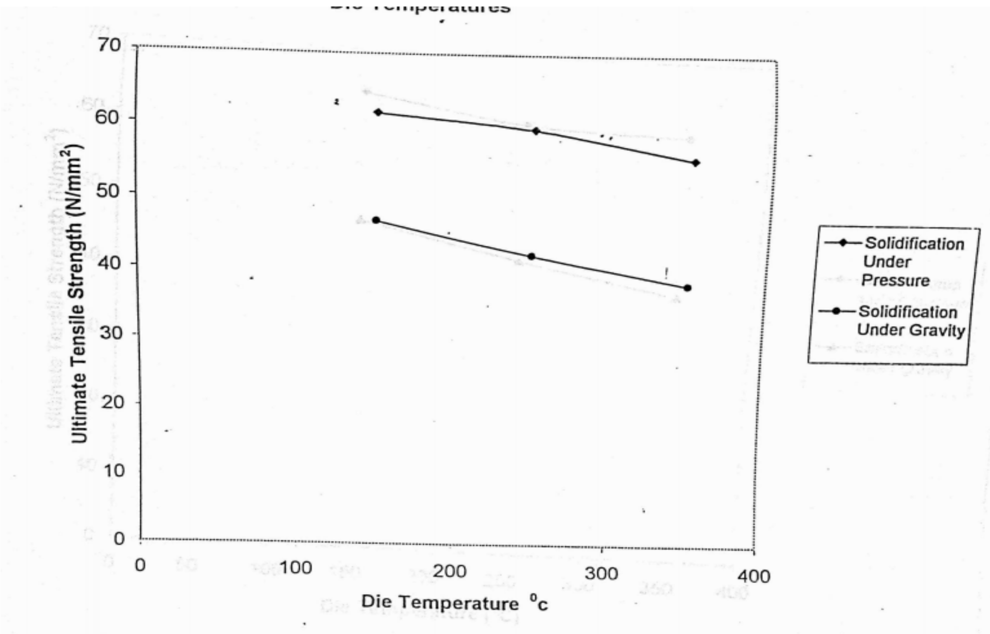

Figure 10 Ultimate Tensile Strength Behaviour of Specimen Cast at 10-ton Load at Different Die Temperatures.

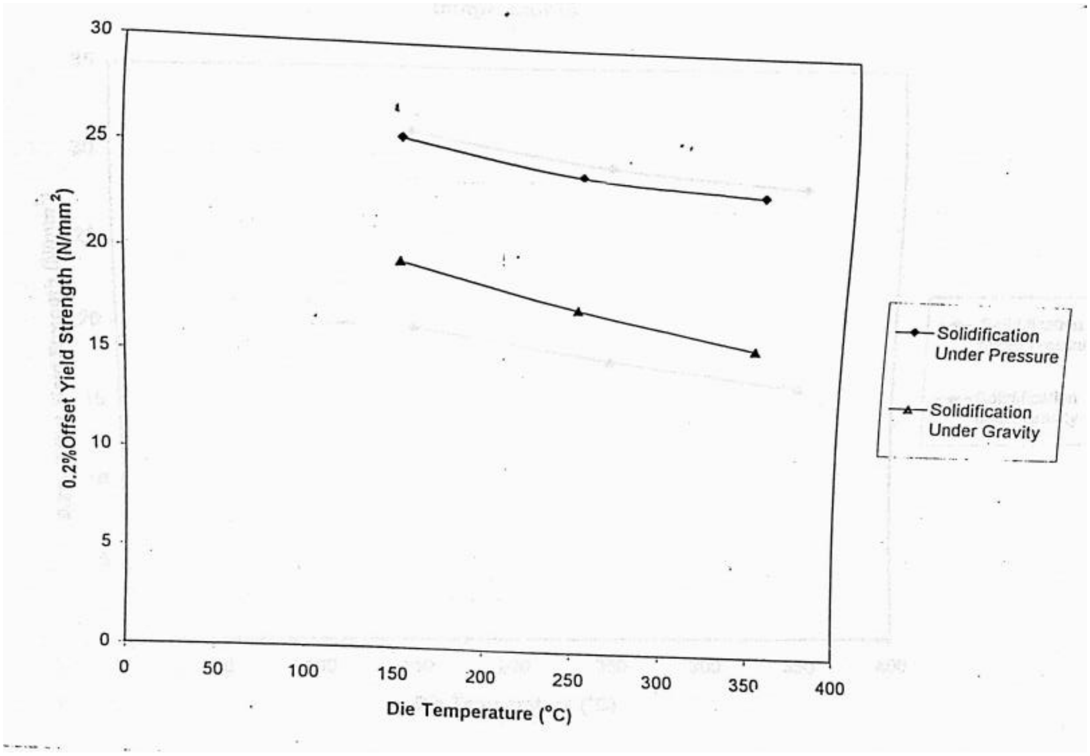

Figure 11 0.2 % offset yield strength of specimen casting at 10-ton load in different die temperatures.

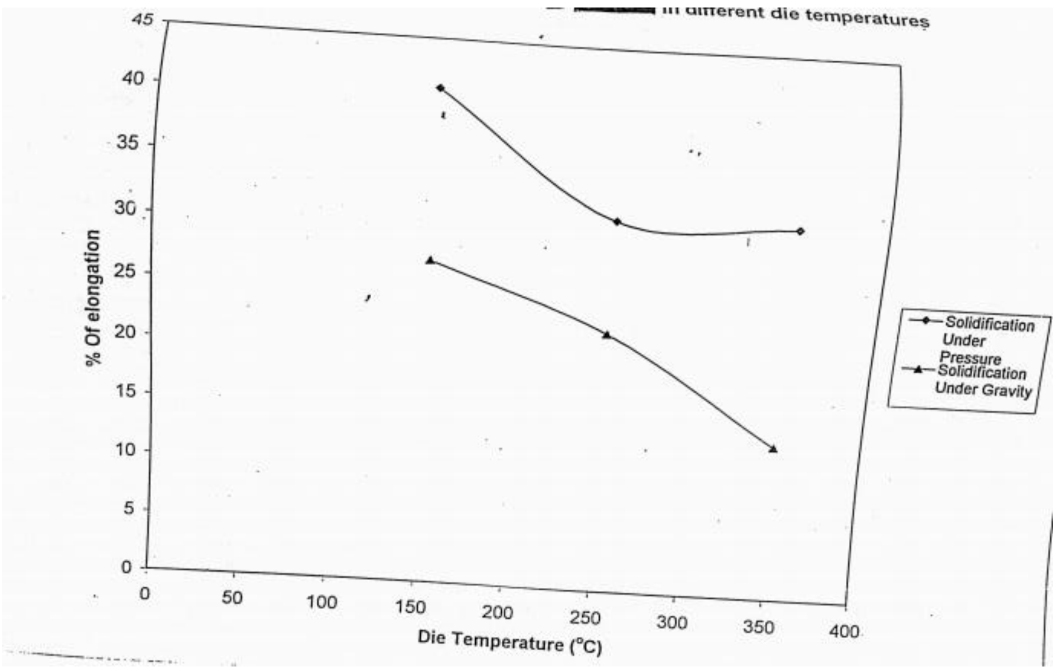

Figure 12 Percentage of elongation specimen at 10-ton load in different die temperature

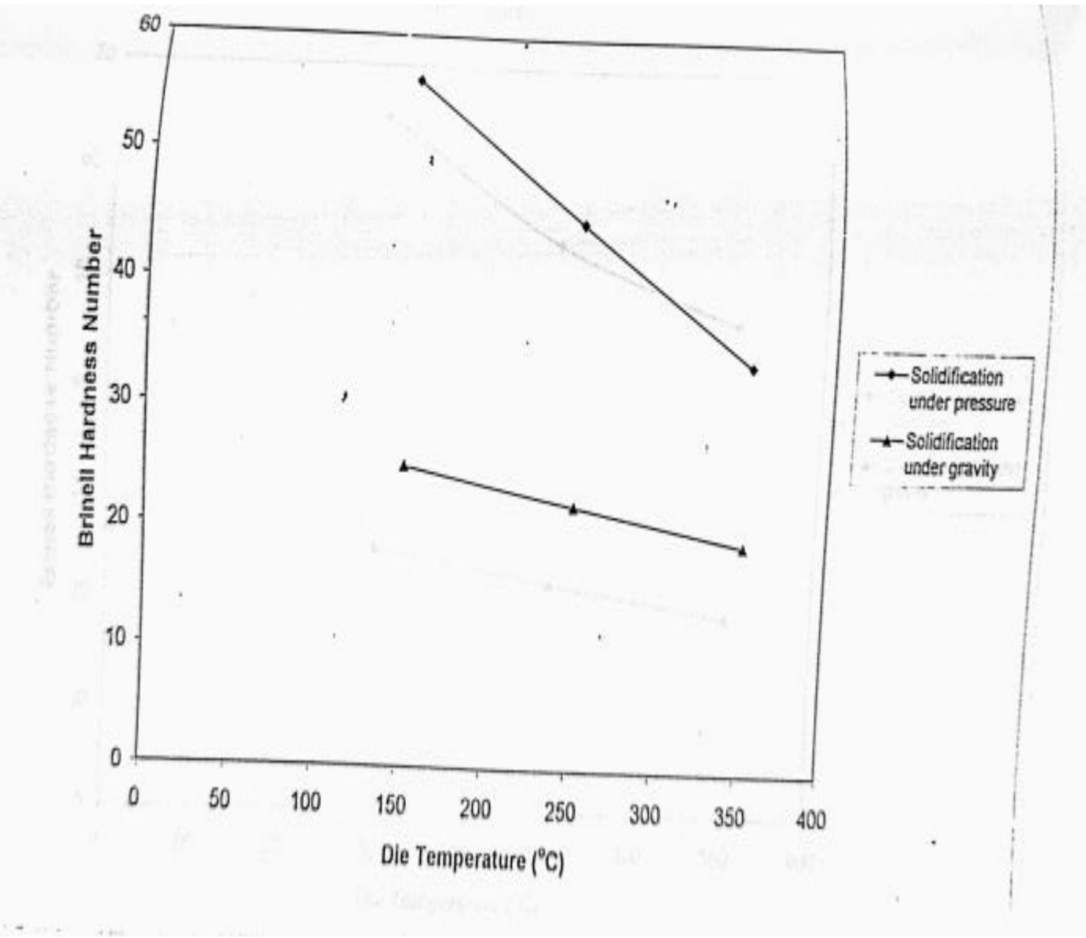

Figure 13 Brinell Hardness number of specimen cast at 10-ton load in different die temperature

(Similarly, the tests such as Ultimate Tensile Strength, Percentage elongation and Brinell hardness been carried out different load (10,15,20) Ton with and different die temperatures)

6. CONCLUSION

The investigation carried out with the LM6 Aluminium alloy clearly reveals the beneficial effect of squeezing improves the mechanical properties like, hardness, ultimate tensile strength, ductility and wear characteristics both at ambient and higher temperatures.

Experiments have been conducted on squeeze casting of LM6 Aluminium at various squeeze pressures from 20 to 80 Mpa in steps of 20 Mpa increase. Properties like hardness, ultimate tensile strength, 0.2% offset yield strength and wear characteristics of the castings are determined. The values are compared with the chill cast.

- Squeezing the liquid metal in the pressure range of 20 to 80 Mpa brings about a distinct improvement in the tensile properties of metal at elevated temperature. The best properties like ultimate tensile strength, 0.2% offset yield strength, hardness, and wear resistance are displayed by the aluminium metal at 80 Mpa, squeeze pressure.
- Microstructure shows uniform distribution of grains in the casting.
- With further increase in squeeze pressure applied, the ultimate tensile strength, 0.2% yield strength, ductility, hardness, of the LM6 Aluminium Alloy is likely to improve further.

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