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Review Article

Investigation of Microstructure and Mechanical Properties of Squeeze Cast LM6 Alloy with Varying Contents of $Al_2O_3$and Si_3N_4 - A Review

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Abstract

Aluminum-based composites find its importance in the field of automobile and aerospace industries owing to their improved mechanical and microstructure properties are utilized for producing cylindrical components in LM6 alloy. Among all types of metal matrix composites (MMCs), considerable attention has been paid towards synthesis and characterization of aluminum matrix composites due to its light weight and ease of processing. Different types of dispersoids like SiC, alumina, Si_3N_4, TiO_2, etc., have been used as reinforcement materials in the form of fibers, whiskers or particulates in aluminum alloy matrix. Among all the available types of composite materials, particle reinforced composites are the most promising ones owing to their, isotropic material properties and low cost. Many researchershave reported that addition of ceramic particles to aluminum matrix do enhance its mechanical properties. Hence, aluminum reinforced with ceramic particles is one of the popular groups of MMCs. However, there exists still problems in producing good quality particle reinforced MMCs.In this view, LM6 alloy with varying contents of Al_2O_3 and Si_3N_4 is going to be fabricated because of its excellent mechanical and microstructure properties like strong bonding, high hardness, good thermal shock resistance, resist strong acid attacks, wear resistance, long life and so on . In addition LM6 alloys reinforced with Al_2O_3 and Si_3N_4 material is not fabricated previously through squeeze casting method. Squeeze casting has its own advantages such as maximum utilization of material, low porosity, good surface finish, near net shape product and so on. All this factors motivates to fabricate the alloy through squeeze casting and to study its characteristics.

Keywords: *Al-MMCs, Squeeze casting, LM6, Silicon nitride, Wear resistance.*

1. Introduction

Casting is a manufacturing process by which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together examples are epoxy, concrete, plaster and clay. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods. Casting is 6000 year old process. The oldest surviving casting is a copper frog from 3200 BC.

1.1Squeeze Casting

Squeeze casting, also known as liquid metal forging, is a combination of casting and forging process. The molten metal is poured into the bottom half of the pre-heated die. As the metal starts solidifying, the upper half closes the die and applies pressure during the solidification process. The amount of pressure thus applied is significantly less than used in forging, and parts of great detail can be produced. Coring can be used with this process to form holes and recesses. The porosity is low and the mechanical properties are improved. Both ferrous and non-ferrous materials can be produced using this method.

The squeeze casting process uses an accurately measured or metered quantity of molten metal which is poured into a heated mould via a launder. The mould is closed to produce an internal cavity in the shape of the required component. The molten metal is forced/displaced into the available space of the die cavity. As with most casting processes, using a permanent pattern, the mould is coated with a suitable release agent and for squeeze casting it is usually in the form of a graphite coating. Pressure continues to be applied to the molten metal until it has solidified and forms the required component. The press is then withdrawn and the component is ejected. Squeeze casting is most suited to the production of light alloy components in large production quantities. Retractable and disposable cores can be used to create complex internal features.

2. Casting quality with respect to performance

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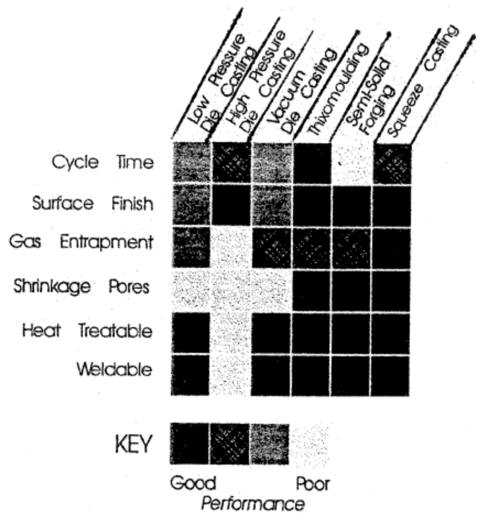
It is beneficial to compare squeeze casting with other casting processes to highlight the advantages of squeeze casting. The overall advantages, based on the cited literature and the authors' own experience, are follows: mechanical properties, fine structure, minimal porosity, heat-treatable, weldable, good surface finish, high productivity.

2.1. Graphical representation of casting quality with respect to performance.



3. Composition of base metal (LM6)

Table.1 Composition of LM6

Copper	0.1% Max
Magnesium	0.1% Max
Silicon	10.0-13.0%
Iron	0.6% Max
Manganese	0.5% Max
Nickel	0.1% Max
Zinc	0.1% Max
Lead	0.1% Max
Tin	0.05%Max
Titanium	0.2%Max
Aluminium	Remainder

Reinforcement used Si_3N_4 and Al_2O_3.

4.0. Review

Squeeze casting (SC) is a generic term to specify a fabrication technique where solidification is promoted under high pressure within a re-usable die. It is a metal-forming process, which combines permanent mould casting with die forging into a single operation where molten metal is solidified under applied hydrostatic pressure. Although squeeze casting is now the accepted term for this forming operation, it has been variously referred to as "extrusion.

Casting" , "liquid pressing", "pressure crystallization" and "squeeze forming" . The idea was initially suggested by Chernov in 1878 to apply steam pressure to molten metal while being solidified. However, in spite of its century old invention, commercialization of squeeze casting has been achieved only quite recently and is mainly concentrated in Europe and Japan. It is mainly used to fabricate high integrity engineering components with or without reinforcement. Hartley reported a technique developed by GKN Technology in UK for the pressurized solidification of Al alloy in reusable dies. In this process a die set is placed on a hydraulic press and preheated, and the exact amount of molten alloy is poured into the lower half of the open die set, the press closed so that the alloy fills the cavity and the pressure maintained until complete solidification occurs (31±108 MPa pressure). External undercut forms can be produced, and using retractable side cores, through-holes are possible. Since the as-fabricated components can be readily used in service or after a minor post-fabrication treatment, squeeze casting is also regarded as a net or near net-shape fabrication route.

High strength, tough aluminium alloys are widely used in transportation, aerospace and military industry due to their excellent mechanical and physical properties. Some of the alloys are Al-Cu cast alloys, LM6, AA7010, Mg-Al-Ca alloy, LM13, A16061, AlSi9Cu3, AZ91-Ca Mg, Zinc-aluminium alloys and so on. Each kind of alloy finds its wide range of application depending on its physical and mechanical properties. In line, many reports have been already studied regarding effect of applied pressure, solidification time, die temperature, pouring temperature and the varying the substitution of reinforcement metals. As a result, tensile strength, ductility, fatigue behaviour is varied. Hence it is important to choose the appropriate optimizing condition based on application. This report focuses the fabrication of LM6 alloy and the aluminium oxide and silicon nitride as a reinforcement material. The following are some of the previous reported works by employing squeeze casting method.

Vijian et al have studied the application of pressure during solidification on the commercially available pure gunmetal (Cu 85%,Zn 5%, Sn 5%, Pb 5%) used for squeeze casting. The alloy was melted in crucible furnace. Once it is degassed, a temperature is maintained at 1300°C and this melt is poured into a pre-heated die cavity. They have found that on increasing the pressure during solidification, there is an increase in hardness, ultimate tensile strength, moderate increase in ductility, increase in density, reinforcement of microstructure, etc. It is also found that the rate of increase of hardness with respect to squeeze pressure is found to be more for the hollow component. Also they have shown the comparison of hardness increase in solid and hollow components with increase of squeeze pressure. Similarly, density is also found to increase more rapidly in solid component. It is interesting to note the high rate of increase of hardness with hollow component, which is the result of both increase of heat transfer rates and decrease of inter-atomic distances. However, it is observed that the rate of increase of density is more for solid components. It is also noted that increase in ductility and ultimate tensile strength with increase in squeeze pressure is seen. Further they have compared the squeeze cast samples with Gravity cast samples and concluded that the squeeze cast samples have better strength–ductility combination along with the refined cell structure.

Yong et al. have studied the zirconium-free (RZ5DF) magnesium alloy metal matrix composite. The squeeze casting process was used to produce the composites and the process variables evaluated were applied pressure, from 0.1MPa to 120MPa, and perform temperature from 250 ◦C to 750◦C. A zirconium-free magnesium–4.2% zinc–1%-rare earth's alloy, designated RZ5DF, was used for this research. Several fibre preform materials, proportions and binder systems, were evaluated to determine their compatibility with the magnesium alloys and the mechanical properties that they delivered to the composite [14]. This preliminary research established that a composite based on a silica-bonded, 14 vol. % Saffilfibre perform delivered the best characteristics in terms of ease of production and maximum 'value to strength ratio'. In the first series of experiments, the effect of applied pressure was evaluated. In the second series, the combined influences of applied pressure and perform preheat temperature were evaluated. The optimum applied pressure for the squeeze casting of RZ5DF-14 vol. % Saffilfibre composites was determined to be 80MPa. At applied pressures below 60MPa, micro porosity was not suppressed. Conversely, a high applied pressure of 100MPa or above causes fibre clustering and breakage and a concomitant reduction in UTS. The optimum perform preheat temperature was established to be 600 ◦C. At this temperature consistent fibre infiltration was achieved and the optimum cell size of 30μm was obtained in the matrix. The optimum combination of applied pressure and perform preheat temperature was determined to be 80MPa and 600 ◦C, respectively. For this combination, a UTS value of 259MPa was obtained. The composite delivered a 30% increase in UTS compared with that developed in the squeeze cast base alloy. Hence they have optimized the pressure and temperature to get good quality casting material.

Hot tensile and fatigue behaviour of zinc–aluminum (ZA-8, ZA-12 and ZA-27) alloys was studied by Fatih Cay, et al . A series of Zn–Al (ZA-8, ZA-12 and ZA-27) alloys were produced as ingots using high purity zinc (99.9%), electrolytic copper (99.9%), commercially pure aluminium and magnesium. The results showed that the composition of the ingots were Zn-8.2 Al–0.9 Cu–0.02 Mg wt.% for ZA-8, Zn–11.5, Al–1.1 Cu–0.02 Mg wt.% for ZA-12, Zn–26.5 Al–2.2 Cu–0.02 Mg wt.% for ZA-27. The alloys were melted in an electric furnace to temperature of 50 °C above liquidous plot for each alloy and poured into permanent mould which was preheated to 100 °C. In squeeze casting process, the liquid metal poured into the die cavity and then the piston with diameter of 100 mm pressurized the liquid metal with a 0.1 MN piston force. ZA-8, ZA-12 and ZA-27 alloys were produced using squeeze and gravity-casting techniques. The microstructure examination showed that small and very tight morphologies had been obtained in Squeeze casting with respect to gravity-casting technique. The tensile properties of the squeeze-cast and gravity-cast alloys at temperatures up to 150 °C have been investigated. Squeeze-cast ZA-27 had the highest tensile and yielding strength at all temperatures followed by gravity-cast ZA-27. Another impressive view of the results is that squeeze-cast ZA-8 has little higher tensile properties than gravity-cast ZA-12 which has high aluminium content. It is thought that the casting technique is an effective factor improving the tensile properties of the alloys tested. The tensile properties of the alloys decreased with increasing the test temperature. At low temperatures, the initial differences in the strength values of the same type alloys depending on the casting method were so large, but the differences in the strength decreased with increasing the temperature. The fatigue resistance of the squeeze-cast alloys were superior to those of the gravity-cast alloys. The squeeze-cast ZA-27 alloy had the highest fatigue resistance among the tested alloys. The squeeze-cast ZA-8 and ZA-12 alloys showed near fatigue resistance to the gravity-cast ZA-27 alloy.

Lim Ying Pio et al have studied the effect of Al5Ti1B on the mechanical properties of LM6 Al–Si alloy sand casting. The typical LM6 aluminium alloy contains 10–13 wt. % of silicon and thus inherently solidifies with coarse grain sizes. The mechanical properties ascertained are hardness and ultimate tensile strength (UTS). The grain macrostructures of the castings are studied by optical and scanning electron microscopes. The experimental work is performed on a sand casting of different modulus, which inherently induces different cooling rates to enable a simple correlation between cooling rate and grain refinement level. The addition level of Al5Ti1B into the melt ranges from 0 wt.% to 1 wt.% with the increment of 0.25 wt.%. The experimental results show that the mechanical properties of LM6 sand casting can be optimally improved by grain refinement of 0.5 wt.% Al5Ti1B. Further increase of grain-refiner quantity does not provide any more significant improvement. They have found that solidification rate is directly proportional to the addition level of grain-refiners but inversely proportional to the casting modulus. In the original sand casting of LM6, section of lower modulus with higher solidification rate has better mechanical properties. When the optimal level of grain-refiner is added, more uniform mechanical properties are achieved throughout the casting irrespective of section modulus. It is found that the inoculation of LM6 Al–Si alloy with grain-refiner Al5Ti1B will improve the mechanical properties of the castings. The hardness can be improved about 10% and the ultimate tensile strength also achieves a significant improvement of 39%. The optimal addition level of grain refiners is found to be 0.5% to achieve the highest values of hardness and ultimate tensile strength in the castings. Grain refinement also increases the solidification rates of LM6 sand castings for all sections of different modulus. Faster solidification rate coupled with more heterogeneous nucleation sites will promote the formation of finer equaled grain sizes. The experimental data concludes that LM6 sand castings can be effectively grain-refined with Al5Ti1B by introducing the master alloy in bar form into the melt just before pouring into the mold. The most optimally potent addition level is 0.5 wt. % to achieve the best mechanical properties of hardness and ultimate tensile strength for LM6 sand castings.

The mechanical properties of Al_2O_3/aluminum alloy A356 composite is manufactured by squeeze casting technique. By varying the volume contents of A356 alloy in Al_2O_3/A356 from 5–40 vol. % and its density and bending strength is studied by Shang-Nan Chouet et al . It isfound that the density decreases linearly with increasing A356 content from 5 to 40 vol. %, and the relative densities of all composites were almost 100%. As the A356 content increased from 5 to 40 vol.%, the hardness decreased substantially from 1109 to 227HV. Upon further increasing the fracture strength decreased from 492.5 to 457MPa. The four-points bending strength of the composites increased from 397 to 482.5MPa with increasing the A356 contents from 0 to 10 vol.%, but decreased from 482.5 to 443MPa on increasing 10 to 40 vol.%. The fracture toughness increased from 4.97 to 11.35 MPa with increasing A356 content from 5 to 40 vol. %. One can fine three toughening mechanisms; crack bridging, crack deflection and crack branching in the composites on SEM micrograph.

Seyed Reihani et al studied the 6061 aluminum matrix composites containing 30vol% SiC with mean mass particle size of 16 and 22 lm as the reinforcing phase synthesized by squeeze casting route. This article presents the effect of SiC particles on the aging behavior, mechanical properties and wears resistance of 6061 aluminum alloy made by squeeze casting method. The SiC preform was made by blending SiC particles with silica as a coal and sintering. The results indicated that a homogenous distribution of SiC particles in the aluminum matrix, which is almost free of pores, is obtained. Higher strength and lower wear rates were observed in the composite materials than the unreinforced aluminum alloy part. However, a marked decrease in ductility of the composites arising from adding of SiC particles was obtained. The aging behavior of the aluminum alloy was found to be influenced by the reinforced materials, i.e. the time to obtain the peak hardness in T6 treatment was lower for the composites than the unreinforced material. The fracture surfaces of the unreinforced and composite samples exhibited dimple surfaces. The wear resistance of the aluminum alloy was improved by reinforcing with SiC particles and it is comparable with unalloyed pearlitic cast iron.

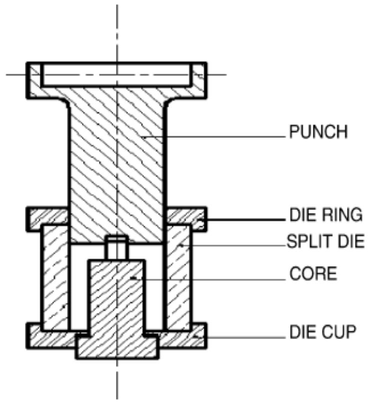
The microstructure and tensile properties of direct squeeze cast and gravity die cast 2024 wrought Al alloy is studied by Hajjari et al. Squeeze casting of 2024 Al alloy, caused the refinement of the microstructure and the reduction of DAS of the alloy. It decreased the porosity and increased the density and tensile properties of the cast alloy. The elimination of porosities was the main reason for increasing the tensile strength of the alloy up to 50 MPa, however above 50 MPa applied pressure, finer microstructure due to higher cooling rates seemed to be the cause of increase in tensile properties.

Effects of applied pressure melt and die temperatures on the microstructure of squeeze cast LM13 alloys were examined By Malekiet et al**.** The results showed that application of pressure during solidification decreased the grain size and SDAS of the primary α phase and modified the eutectic silicon particles. With application of an external pressure of about 100MPa, the average SDAS and the average aspect ratio of eutectic silicon particles were reduced from47μm and 5 to about 34μm and 1.5, respectively. SDAS of the primary α phase and the average aspect ratio of eutectic silicon particles decreased slightly with a drop in the melt or die temperatures, reaching to 32μm and 1.25, respectively, for the best conditions. No significant change in the morphology of primary α phase was observed with melt temperature. However the SDAS of primary α phase and the average aspect ratio of eutectic silicon particles decreased slightly with a drop in melt temperature rendering more desirable microstructures. The effect of die preheating temperature is similar but more pronounced than those of melt temperature in the range examined. The effects of casting parameters on the microstructure of LM13 alloy can be justified based on the effects of applied pressure on the thermal grain refinement or modification of the microstructure. These include change in the melting point of the alloy, possibility of occurrence of a prompt large under cooling in the melt and improved heat transfer across the die-metal interface.

A study on the effect of squeeze casting parameters on the mechanical properties of AZ91 Mg alloy with 2 wt. % Ca incorporated was investigated by Goh et al . The parameters studied include squeeze casting pressure, melt temperature and mould temperature. It was found that a squeeze casting pressure of 111 MPa and a melt and mould temperature of 800 °C and 200°C respectively gave a good combination of tensile and hardness properties in AZ91–2Ca Mg alloy. Finally they have concluded that the Microstructural refinement due to under cooling indicated by the mould temperature and superheating due to the relatively high melt temperature results in better mechanical properties for the present AZ91–2Ca alloy.

The effects of applied pressure during solidification on the microstructure and mechanical properties of cylindrical shaped ductile iron castings were investigated. Magnesium treated cast iron melts were solidified under atmospheric pressure as well as 25, 50 and 75 MPa external pressures. Microstructure features of the castings were characterized using image analysis, optical microscopy, scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) techniques. Tensile properties, toughness and hardness of the castings were also measured. The results showed that average graphite nodule size, free graphite content and ferrite content of the castings decreased and pearlite and eutectic cementite contents increased as the applied pressure was raised from 0 to 75 Mpa. Graphite nodule count was first increased by raising the applied pressure up to 50 MPa and then decreased. The highest graphite nodule count was obtained at 50 MPa applied pressure. The micro structural changes were associated with the improved cooling rate and the expected changes in the corresponding phase diagram of the alloy under pressure. The ultimate tensile strength (UTS), yield point strength (0.2% offset) and fracture toughness of the castings were improved when the applied pressure was raised from 0 to50 MPa. Further increase of the applied pressure resulted in slight decrease of these properties due to the formation of more cementite phase in structures as well as reduced graphite nodule count. Hardness of the castings continuously increased with increasing the applied pressure.

3.1 Punch and die arrangement of squeeze casting



Mohsen Masoumi et al have studied the Influence of applied pressure on microstructure and tensile properties of squeeze cast magnesium Mg-Al-Ca alloy. Mg-5wt.%Al-1 wt.%Ca (AX51) alloy was used for the investigation. The alloys contain primary α-Mg (Al,Mg)Ca intermetallic and Mn-Al intermetallic phases. Due to the high aspect ratio of the casting geometry, no significant improvement in grain structure was observed as the applied pressures increased. The results of the tensile testing indicate that the mechanical properties, UTS, YS and elongation, increase with an increase in the applied pressures during solidification. The material densification and reduction in second phase fraction are deemed to be responsible for the increase in tensile properties. The observation via SEM fractrography and tensile results indicates that, as the applied pressures increase, the fracture mode become more ductile.

The effects of Mn content on the microstructures and mechanical properties of squeeze cast Al-5.0Cu-0.5Fe alloys at different applied pressures were examined by Wei-wen ZHANG et al [20]. The tensile test, optical microscopy, scanning electron microscopy and image analysis have been carried out for this sample. The results show that the needle-like β-Fe phase (Al_7Cu_2Fe) is completely converted to the Chinese script α-Fe phase($Al_{15}(FeMn)(CuSi)$) when the applied pressure is 0 MPa and the Mn/Fe mass ratio reaches 1.6. As to squeeze casting, the Mn/Fe mass ratio of 0.8 is demanded for the complete conversion of β -Fe phase to α -Fe phase at the applied pressure of 75 MPa. The lower Mn content, i.e., the less Mn/Fe mass ratio, for squeeze cast alloy is due to the small size and less content of the Fe-rich phases. Excessive amount of Mn, however, deteriorates the mechanical properties because of the increase in the total amount of α -Fe and the porosity that associates with the excessive brittle phases.

Shi-bo BIN et al have investigated the Influence of technical parameters on strength and ductility of AlSi9Cu3 alloys in squeeze casting and an orthogonal test was conducted. The experimental results showed that when the forming pressure was higher than 65 MPa, the strength (σb) of AlSi9Cu3 alloys decreased with the forming pressure and pouring temperature increasing, whereas σb increased with the increase of filling velocity and mould preheating temperature. The ductility (δ) by alloy was improved by increasing the formingpressure and filling velocity, but decreased with pouring temperature increasing. When the mould preheating temperature increased, the ductility increased first, and then decreased. Under the optimized parameters of pouring temperature 730 °C, forming pressure 75MPa, filling velocity 0.50 m/s, and mould preheating temperature 220 °C, the tensile strength, elongation, and hardness of AlSi9Cu3 alloys obtained in squeeze casting were improved by 16.7%, 9.1%, and 10.1%, respectively, as compared with those of sand castings.

5. Conclusions

In this reviewLM6 material is chosen as a base material and reinforcement material as Al_2O_3 and Si_3N_4, because of their excellent mechanical properties mentioned in this survey.Literature works were carried out on the selected materials and techniques which shows increase in mechanical and metallurgical properties

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