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Microstructure, double shear and tribological properties of A356 aluminum alloy fabricated by gravity, vacuum and squeeze casting method

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Abstract

A356 alloy produced by the means of gravity die casting, vacuum casting and squeeze casting have been investigated along with a comparison of their microstructure, mechanical and tribological properties. The microstructure of the conventional gravity cast samples are fully dendrite where as vacuum and squeeze cast are contrast to spheroidial morphology. The mechanical properties of the squeeze cast samples are considerably higher than the gravity and vacuum casting samples. The volumetric wear loss and coefficient of friction in vacuum casting samples are always less than those in gravity and squeeze casting samples at all loads. The surface roughness value of squeeze cast sample was less compared to gravity and vacuum casting.

Keywords: A356 alloy, Gravity casting, Vacuum casting, and Squeeze casting, Microstructure, Double shear strength, Wear test, Surface roughness.

1. Introduction

Among different aluminum alloys, A356 alloys are widely used commercially in industries like automobile and other applications because of its low density, electrical conductivity and corrosion resistance. The present needs for light weight materials with high strength and high stiffness have attracted much interest in the development of A356 alloy. A356 alloy have excellent castability, corrosion resistance and high strength-to-weight ratio, which increase performance and fuel economy, make Al-Si-Mg casting alloys suitable materials for various application in the automotive industry, such as engine blocks, pistons, cylinder heads, and cranks. The conventional casting often contains internal structure defects, such as oxide and gas entrapment, shrinkage porosity that leads to poor mechanical properties.

To achieve better properties there is an increasing trend to produce common A356 alloys automotive components by vacuum casting. The vacuum counter-pressure casting technology is a kind of advanced counter-gravity method and has been employed widely in precision forming field. Generally speaking one of the keys to obtain high quality products for vacuum counter-pressure casting is, the control of crystallization and solidification, which ensures castings possess good solidification feeding condition and dense microstructure with excellent mechanical properties. Moreover, holding pressure is a important parameter for vacuum counter-pressure casting technology and significantly affects casting quality [1]. At present, vacuum counter-pressure casting techniques have been studied as a focal problem in the foundry industry.

Squeeze casting is an advanced manufacturing process where molten metal is subjected to high applied pressure during cooling and solidification [2, 3]. The advantage of the squeeze cast products are mainly near-zero gas porosity or shrinkage porosity, better mechanical properties and reduced metal wastage. It has been reported that the mechanical properties of a squeeze cast item can be as good as wrought products of similar composition [3, 4].

The squeeze casting process has significant benefit over other gravity casting and vacuum casting process including [5]:

(i) Near net shaped manufacture in one step from a liquid
(ii) Refined grind structure
(iii) Improvement mechanical properties
(iv) Virtual elimination of all shrinkage and gaseous porosity
(v) Surface finish, 0.4-3.2µm
(vi) Dimensional accuracy is also good 0.2mm/100mm

To achieve better properties, there is an increasing trend to produce A356 Al alloy by squeeze casting. Hence, an attempt to go for A356 alloy by gravity (g.c), vacuum (v.c) and squeeze (sq.c) casting are made here. As squeeze cast components are reported to have superior mechanical properties, fine microstructure and minimal porosity [6], the process was with squeeze casting.

Results on squeeze casting of light alloys and their composites [7] showed that the process is most suitable for opening up new possibilities for the production of castings that are subjected to high service stresses, improvement of all the mechanical properties can be found in squeeze casting method for all the light metal composites. A.K.Dey et.al studied mechanical and wear properties of rheocast and conventional gravity die cast A356 alloy [8].The microstructure of conventional cast samples are fully dendritic where in rheocast samples, the primary phases are of rarely spheroidal morphology. Rheocasting offers superior wear resistance compared to conventional castings. The wear loss increases with increasing load in all samples. Coefficient of friction for the rheocast samples is lesser than the conventional cast samples at all the loads.

QingSong Yan et.al investigated the effect of holding pressure on the microstructure of vacuum counter-pressure casting aluminum alloy [9]. Their results showed that, with an increase in holding pressure, the extrusion and infiltration ability among dendrites gets strong and the microstructure of vacuum counter-pressure casting aluminum alloy samples at the same location becomes finer, more uniform and denser. Vacuum assisted high pressure die casting of aluminum alloys was examined by X.P.Niu (Chair) et.al [10]. It was identified that the volume of gas porosity and the pore sizes in the castings were significantly reduced by using vacuum assistance during the die Casting. As a result, the density and the mechanical properties, particularly the tensile strength and ductility were improved.

Report on counter gravity infiltration casting technique to make A356 alloy [11] showed that the macro-defect free aluminum foams can be produced by the method of counter-gravity infiltration casting and the foam materials thus obtained exhibit excellent mechanical properties. The void content is an important influencing factor on the mechanical properties of aluminum foams and the yield stress significantly increases as void content decreases.

Microstructure characterization and tensile properties of squeeze –cast Al-Si-Mg alloys was analyzed by M.T. Abou El-khair et. al [12]. It was identified that with an increase in squeeze pressure the hardness and tensile properties increased along with a decrement percentage of porosity and also an increase in density. Squeeze and gravity casting technique have been used to analyze the tensile and wear properties of aluminum composites [13]. It was identified that significant improvement in tensile strength and wear resistance.

Report on squeeze casting technique to make A356 Al alloy [14] showed that the significant variability in fracture related mechanical properties, such as ductility and strength. Squeeze casting methods was used to make A356 semi-solid Al alloy [15] and it revealed that there is a decrease in the grain size along with an improvement in the morphology of primary α-Al and also further increase in pressure the density and the tensile properties improved.

The most important challenge during fabrication of A356 alloy in the liquid phase processes are base metal with less porosity, higher density and mechanical properties. To overcome these challenges; by gravity casting, vacuum casting, squeeze casting techniques have been adopted in this study. Moreover, literature reports common mechanical properties in terms of microstructure, hardness, tensile and compressive strength. But, the present work elaborates microstructure, double shear strength along with tribological properties of A356 alloy.

2. Experimentation

2.1. Materials and Manufacturing process

Table 1: Chemical composition of A356 Aluminum alloy

Chemical compositions	Cu	Si	Mg	Mn	Fe	Ti	Ni	Zn	Tin
Wt %	0.099	6.65	0.55	0.06	0.32	0.061	0.04	0.004	<0.001

The matrix alloy used for the present study is A356 alloy which has chemical composition in weight percentage as in Table 1.

The chemical composition analysis was carried out as per ASTM E1251-07 OES standards.

In the gravity condition, after pouring the molten metal, the die setup was cooled by circulating water around the die wall, which enhances the mechanical properties of the casting by this cooling effect. The final solidified cast part was taken out from the die. The vacuum casting unit is also attached in the same machine. The die setup is split die AISI 310 high chromium and high corrosive stainless steel material has been used. Before pouring the molten metal, the vacuum pump has been run and the air has been suck from inside split die, within 0.75ms. During vacuum condition the molten metal has been poured into the die. After solidification, the casting part has been taken out from the split die.

Aluminium Stir Casting Furnace
With Vacuum Casting & Squeeze Casting

Parts:

1. Stirrer motor assembly
2. Stirrer
3. Pre-heating furnace for nano particles
4. Furnace
5. Pathway heater
6. Squeeze casting setup
7. Nano particle pre-heating furnace temperature
8. Pathway heater temperature
9. Vacuum gauge
10. Hydraulic power pack for squeeze casting
11. Control Panel

Figure 1: Gravity, Vacuum and Squeeze casting electric furnace.

The squeeze casting unit is also interconnected with this machine. After melting the molten metal, the bottom pouring valve of the furnace was operated using automatic control to pour the molten metal through the taper pipe channel connection into the mild steel die. At this movement the squeeze piston was simultaneously activated to squeeze the molten A356 alloy as shown in figure 1. The sliding wear tests were carried out using pin-on-disc tribometer. The pin of 8mm diameter and 27mm length were fabricated and made to slide against a low alloy steel disc of diameter 215 mm and hardness 62 RC. The track diameter and the disc speed were maintained at 0.11m and 100 rpm respectively to maintain at constant sliding velocity of 0.628m/s.

Three loads 10N, 30N and 50N were applied for each test materials. The coefficient of friction were measured continuously with a electronic sensor attached to the machine and recorded, frictional force in Kg and cumulative wear loss in µm were measured from the sensor output as a function of time. The wear test was carried and for a total sliding distance of about 1100m. The final solidified A356 alloy was taken out from the die. After solidification of three (g.c, v.c, sq.c) castings with the dimension of diameter of 46 mm and length 260 mm.

2.2. Specimens preparation

Different samples were prepared for micro structural analysis, hardness, bending and double shear test. SiC emery papers of various grades up to 1200 grit size in wet condition were used for polising. Further, the fine polishing of specimens were carried out using alumina paste and 1µm diamond paste. As per ASTM E3 standard, the fine polished samples were etched using Keller's reagent (2.5% HNO_3 + 1.5% Hcl + 1% HF + 95% H_2O). The micro structural examination was carried using optical microscope with 500 X magnification.Double shear tests were conducted using 200 KN capacities UTM with the help of double shear chuck arrangement. Sample sizes were 10 mm in diameter and 100 mm in length as per ASTM B769-11 standards. The size of the specimen was 8mm in diameter and 27mm in length as per ASTM G-99 standards. After wear the test, surface roughness was evaluated by surf test as per ASTM SJ-301.

3. Results and Discussions

3.1 Microstructure observations

Typical optical microscope images showing the microstructure of A356 Al alloy are as in Figure 2.

(a) (g.c) (b) (v.c) (c) (sq.c)

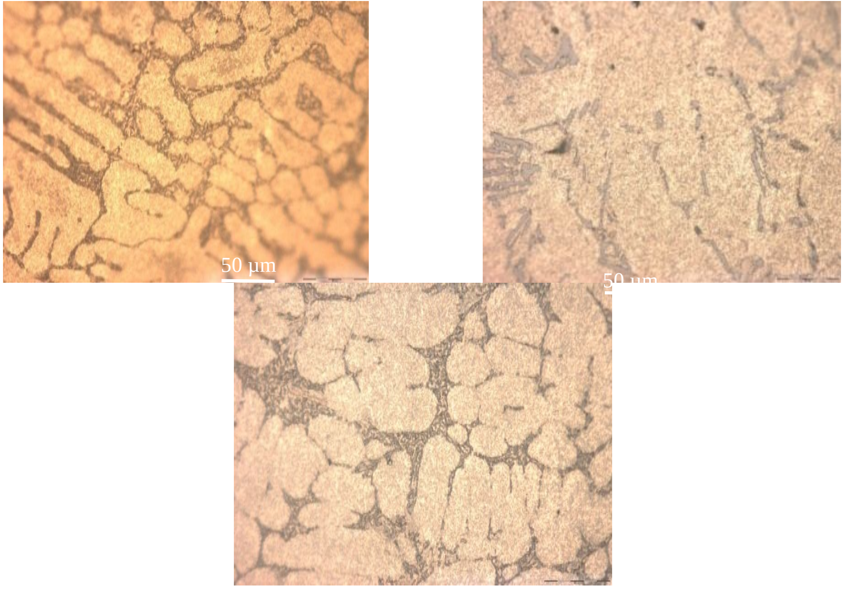

Figure 2 (a-c): Microstructure image of the as cast A356 alloy with 500X magnification.

Figures.2 (a-c) shows the optical microstructure as cast ingots of gravity casting, vacuum casting and squeeze casting. As cast microstructure of these three casting shows that phases are uniformly distributed, the coarse dendrites are observed, and many large porosity defects are also observed in the gravity casting process. Typical dendrites, porosity defects and plate-like silicon particles can also be observed in the microstructure obtained. The microstructure of A356 aluminum alloy fabricated by vacuum casting mainly consisted of α-Al primary solid phase, eutectic silicon particles and Mg_2Si phase. Microstructure of squeeze cast sample has large numbers of finer silicon particles compared to gravity and vacuum cast samples.

3.2 Double Shear

Figure 3 shows the double shear strength of A356 alloy from gravity casting, vacuum casing and squeeze casting processes. It can be obviously observed that the double shear strength of squeeze casting have great improvement compared to gravity and vacuum casting process. The A356 alloy of squeeze casting samples showed higher bending strength of 119MPa (6% higher), compared to gravity and vacuum casting in as cast condition.

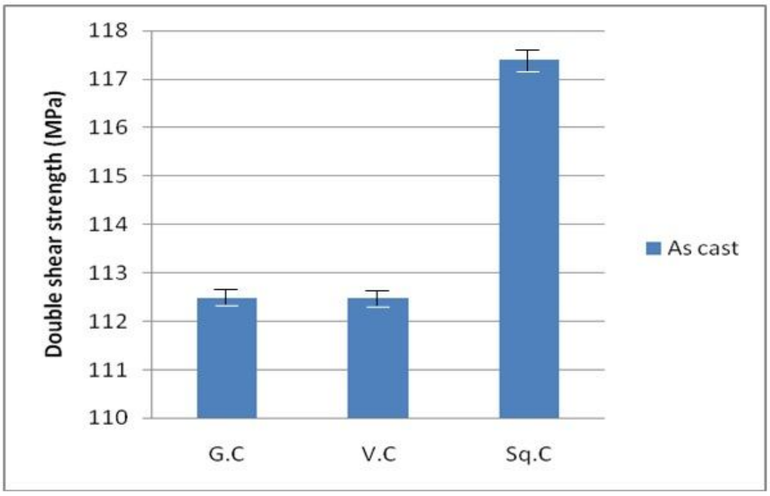

Figure 3: Variation of double shear strength.

3.3 Wear Test at wet condition

The results of wear test of the A356 alloy are shown in Figure 4. The gravity cast and squeeze cast of A356 alloy shows an increase in the wear volume loss. The conventional gravity casting often contains internal structural defects such as oxide and gas entrapment, shrinkage porosity which leads to poor wear properties.

In squeeze casting, due to the presence of a large number of smaller and finer silicon particles, the gravity cast and squeeze cast wear loss were same. Both the curves are matched in same line are shown in Figure 4. In the vacuum cast of A356 alloy shows the decrease wear volume loss due to the vacuum assisted die casting reduces the amount of entrapped air or gas in the die cavity. Metallurgical analysis indicated that casting produced with vacuum assistance one of the greater soundness them, those without the volume of gas porosity was significantly reduced and the size of the porosity was considerably smaller. As a result the wear properties improved significantly.

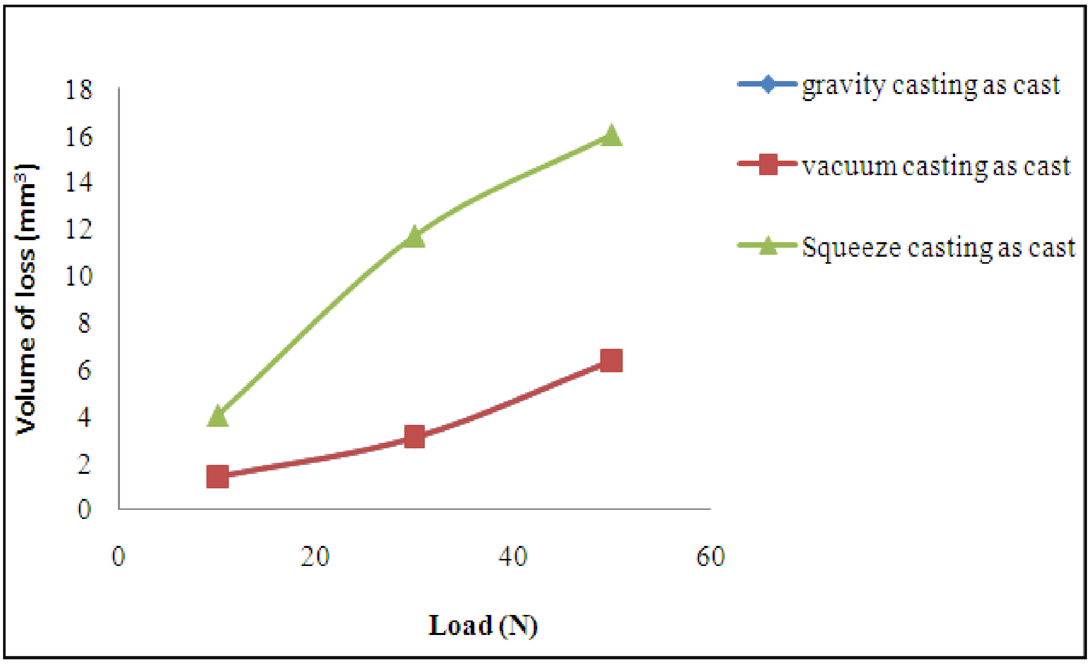

Figure 4: Variation of volume loss.

3.4 Coefficient of friction at wet condition

The results of coefficient of friction test of the A356 alloy are shown in figure 5. The gravity and squeeze casting of A356 alloy shows an increase in the coefficient of friction value. The gravity casting often contains internal structure defects such as oxide & gas entrapment and shrinkage porosity that lead to poor coefficient of friction. In squeeze cast process, molten metal is cooled and solidified at a very high level of pressure over 600 MPa. The time required for solidification is substantially reduced due to enhanced heat transfer at the mould surfaces under high pressure that leads to increase in mechanical properties and thus reduced the coefficient of friction compared to gravity casting.

The resulting cast components demonstrate that, the vacuum assisted die casting reduces the amount of entrapped air or gas in the die cavity. Metallurgical analysis indicates that castings produced with vacuum assistance are of greater soundness, the volume of gas porosity was significantly reduced and the size of the porosity was considerably smaller. As a result, the coefficient of friction was very low compared to gravity and squeeze casting.

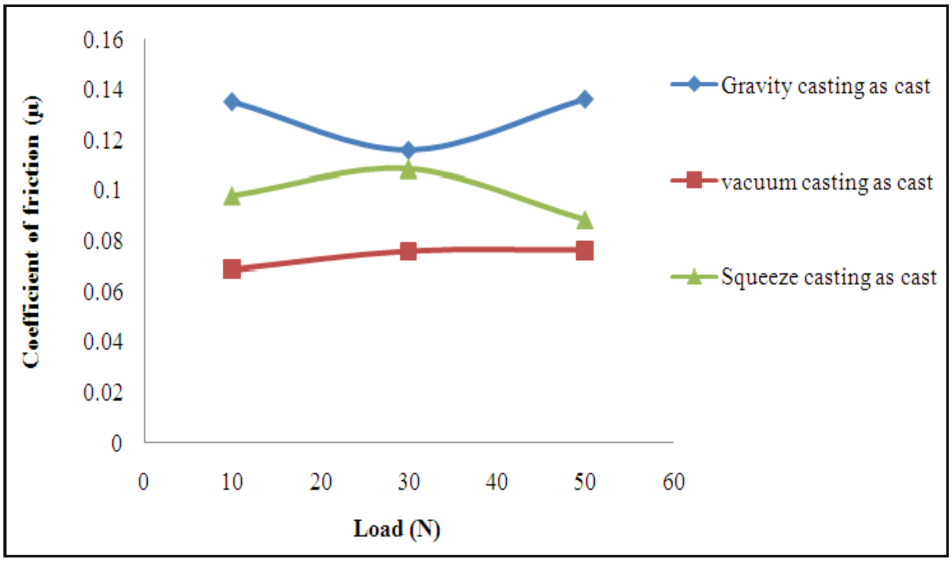

Figure 5: Variation of coefficient of frictions.

3.5 Surface roughness Test

The results of surface roughness test of A356 Al alloy are shown in figure 6. The gravity cast of A356 Al Alloy shows an increase in the surface roughness value (Ra) in microns, due to the typical dendrite, porosity defects and plate like silicon particles compared with vacuum and squeeze casting.

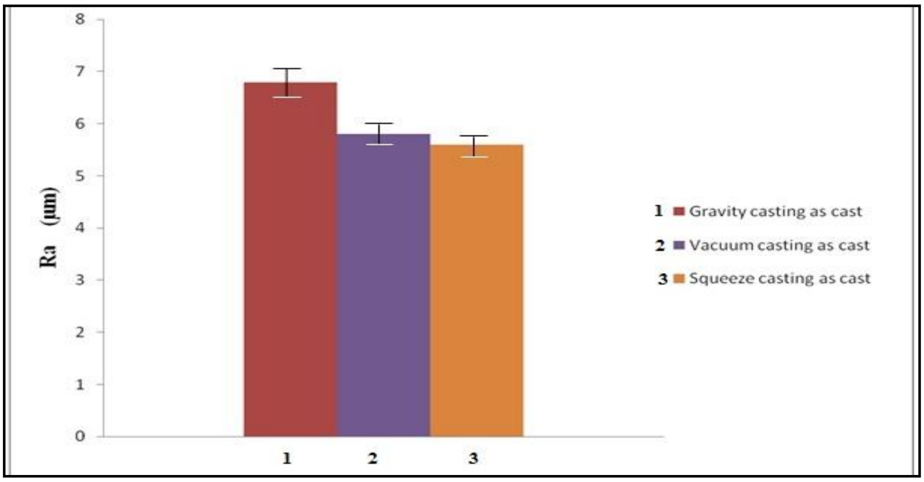

Figure 6: Variation of surface roughness.

The resulting cast components demonstrate that the vacuum assisted die casting reduces the amount of entrapped air or gas in the die cavity which reduces the roughness of the casting compared with gravity cast samples. In the squeeze cast of A356 Al alloy shows a decrease in surface roughness value due to the presence of large number of smaller and finer silicon particles in as cast condition.

Conclusion

1) The conventional gravity casting often contains internal structural defects such as oxide and gas entrapment, shrinkage porosity and gas porosity that leads to poor mechanical properties and tribological properties.
2) The vacuum assisted die cast reduces the amount of entrapped of air or gas in the die cavity. Metallurgical analysis indicates that casting procedures with vacuum assistance one of the greater soundness without gas porosity. As a result, the higher the mechanical properties, the better the tribological properties in terms of wear loss and coefficient of friction.
3) In the squeeze cast process the molten metal is cooled and solidified at a very high level of pressure. The time required for solidification is substantially reduced to enhanced heat transfer at the mould surface under high pressure that leads to higher mechanical properties of double shear strength 112.5-117.5MPa compared to gravity and vacuum cast. The values of coefficient of friction and surface roughness were found to be very low in squeeze cast.

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