Evaluation of Mechanical and Wear Properties of AA2024 Through Co$_2$ Casting Using Silica Sand

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Abstract: Silica sand is generally used moulding sand in the casting industries and majority of the castings produced worldwide because of its easy availability and binding properties. In the present study, silica sand is taken as moulding material and studies the effect of different shapes on the mechanical and wear properties, micro hardness and wear tests. For this casting the selected material (AA2024) into two different shapes (cube and cylinder) using silica sand as the moulding material and study the effect of split piece pattern on the properties and wear of the casted components. Co$_2$ casting is chosen as the industrial process and study mainly focused on to produce the defect free surfaces on AA2024 with split piece pattern which is difficult to control. Destructive tests like hardness, surface roughness are conducted and wear properties of the components is also observed. It is observed from the results that cylinder component has higher hardness due to the faster cooling rate, lower surface roughness and lower wear rate. Analysis concluded that Co$_2$ process is better working for the cylinder type of objects.

Keywords: Silica, AA2024, Co$_2$ process, cylinder.

1. Introduction

Aluminum alloys are used widely for various applications due to their lightweight and specific strength. In particular, transportation and automotive industries most often offer the Aluminum due to the greenhouse effect. Therefore, modifying the properties is an alternative way to promote the alloys for using them effectively. Adding various elements to the substrate resulted in improving mechanical properties, thereby microstructure characteristics. The casting process is one of the most suitable ways to make substrates changes with low cost and high quality. Most of the new alloys were investigated to determine their behavior during the casting and following treatment. A study was previously performed on Al and 4.5 Cu alloys using Co$_2$ casting method [1]. The casted parts were compared to the mechanical and wear properties [2].
In general, the casting process involves the formation of several undesirable effects while making the new alloys. Most of them were related to solidification defects due to insufficient amount and improper mixing of elements into substrates. Therefore, the final product may for the presence of micro cracks and the crystalline structure. Greensand mold casting leading the manufacturing units most effectively compared to other methods. Some researchers were studied on AA6061 by varying the sand permeability and pouring temperature [5]. Also, Co$_2$ casting was also making its way to use it in the casting industries in now a day because of its ease of making the mould. It contains mainly of pure silica sand mixed with sodium silicate and by passing the Co$_2$ gas through holes made in the mould which makes it stronger to hold the pressure made by the molten metal. Almost every manufacturing unit using this method raised its usage in the casting industries. This sand's primary sources are from the coastal lines and every foundry industry importing in a considerable range. Huge quantities of silica sand preferred to be used in the workshop applications as a molding material to produce ferrous and non-ferrous castings.

The alloys AA2024 suffer severely from various casting defects on both surface and subsurface of the components. The cause of these defects is due to multiple sources such as shape of the element, design, type of material and process parameters. The quality of castings drastically improves only through the sand's quality and properties, such as molding sand's physical and chemical properties. These properties vary with the physical properties like size, shape, and density; and also chemical properties of chemical composition [6]. The output of the silica sand casting results was highlighted with the casting parts’ remarkable properties and the reduction of the defects. Srinivas et al. [7] reported that the LM24 Al alloy exhibited the properties through the silica sand casting method excellent than the other casting methods. It was also said that the Silica sand has an influence on the improvement of grains and changes its shape into a spherical shape with a combination of fine and coarse sizes [8].

Therefore, the present study aims to use the silica sand moulds for the AA2024 alloy. Co$_2$ casting was used to produce the components which were of different shapes namely Cube, Gear, Flat plate and Cylinder. Here the different shapes of the components were taken in which two were prepared by split piece pattern (Cube and cylinder). The main objective of the study is to produce the defect free components with best suitable component by silica sand as moulding sand through Co$_2$ casting process out of these components. To study the best various tests were performed on the components like Micro hardness, surface roughness and wear properties of the components.

Additionally, heat transfer rate through the sand also performed to study the flow rate of heat through the silica sand particles to know the cooling rate of the components which makes the components to stronger or weaker by forming the coarse and fine grains. Co$_2$ casting is performed with 6% of sodium silicate as a binder by passing the Co$_2$ gas for 15 sec. Two components of same volume were taken for the comparison study between it. With this study, for AA2024 alloy which pattern shape of component was best suitable to use through Co$_2$ casting can be done.

### 2. Experimental Procedures

Aluminum alloy AA2024 is used for the present study. The alloy was received in wrought form and is cut into small pieces for the ease of performing the casting and the chemical composition of Mg 1.1%, Cu 4.3 %, Cr 0.55%, Fe 0.4%, Si 0.5%, Mn 0.60%, Ti 0.10%, Zn 0.16%. Silica sand is mostly used sand in the present casting industries with nearly 96% of silica grains with other impurities of 4 %. The sand was than cleaned thoroughly in the sieve to remove all the foreign particles and dust and is used for the casting Cube and Cylinder.

The silica sand is weighed in the weighing machine to add the sodium silicate, for every 100 % of weight 92% of silica sand and 8 % of sodium silicate was added to get the molded silica sand. The silica sand was weighed 92% in the weighing machine and it was kept in a tray and 8 % of the sodium silicate...
weighed again in the weighing machine and added to the tray and it was mixed with hands thoroughly until it completely gets mixed. The prepared sand was used for filling all the moulds. For every casting 14 kg of silica sand was used for filling the mould. The silica sand used for the casting was shown in Figure 2.0

The composition of the silica sand was given in Table 1. Before the usage of the silica sand on to the casting firstly preheating is done to remove the moisture content.

| Element | SiO$_2$ | CaO | FeO | Al$_2$O$_3$ | MgO |
|---------|---------|-----|-----|-------------|-----|
| Silica Sand | 96.62 | 0.57 | 1.02 | 1.54 | 0.57 |

2.1 Casting process

Pattern was the replica of required casting and for the present study it is made of the wood as shown in Fig. Wood is chosen because of its easy availability, low weight, easily shaped and most importantly cheaper. Two patterns are prepared in total of the same volume and they were cube and cylinder.

Mould is prepared for all the components with by taking the silica sand of 94 % and 6% of sodium silicate for every 1 kg of the moulding sand. Silica sand and sodium silicate is mixed thoroughly and is filed in the drag part by placing the patterns. Ramming was applied gently on the mould after filling the mixed sand. After that on the cope part sprue and riser is placed and again filled it with the sand, similarly it is also gently rammed to make the mould stronger enough to withstand the pressure exerted by the molten metal. For cube and cylinder the pattern was placed in both the drag and cope part as they are split piece patterns. Mould preparation is shown in the Figure 1.

![Figure 1 Mould Preparation for the casting](image)

After the mould preparation is done the aluminum cut pieces are properly cleaned and placed in the graphite crucible. Crucible furnace is used for the melting of AA2024 alloy. It is set to 700°C as it is the pouring temperature as shown in Figure 2. Graphite crucible is placed into the furnace slowly with the help of pair of tongs. Soon after the furnace reaches to the pouring temperature, the AA2024 started melting and after it reaches to molten state it is taken out carefully and poured in the cavity. After that the
temperature was measured at 8 points for 50 minutes thereafter it is left for cooling down to room temperature. For two components similar process was adopted.

Zwick Vickers’s hardness tester is used for measuring the hardness of casting components at three different spots and taken as an average of it. The load of 0.3 kg applied for 15 seconds. Tally surf used to measure the surface roughness of the all the components to study the surface quality.

The equipment used for the wear test is pin on disc tester model TR-20 LE, which is used for knowing the wear rate of all the casting components. The wear test was conducted at two rotational speeds which were at 600 rpm and 780 rpm at a load of 2 kg was used for the study for all the components. The sliding distance of 600 m was taken to study the wear characteristics of the components.

![Melting Furnace](image)

**Figure 2.** Melting Furnace used for melting

### 3. Results & Discussions

#### 3.1 Hardness Properties

Hardness is a measure of resistance offered by a material to localized plastic deformation induced by either mechanical indentation or abrasion. Hardness of the different shaped components like cube and cylinder was calculated using Vickers hardness test using a diamond shaped indenter. The Vickers hardness test is used as an alternative to the Brinell method to measure the hardness of materials as it is easier to use than other hardness tests. It has widest scales among hardness tests and can be used for all
metals. From the hardness values obtained graph is plotted for the two shapes and from the graph, the following results are obtained.

![Figure 3. Comparison of Hardness values vs Specimen Shape](image)

The hardness profile of the silica sand for different shapes of casting components were shown in Figure 3. The microhardness profile showing that the higher microhardness shown at cylinder component i.e., 137.6 Hv compared with the other and lowest microhardness observed at cube component with 122.1 Hv. It is because of the grain size of the cylinder was finer than the remaining components and also the cooling rates were higher in the cylinder compared to the other component. It is evident that also the thermal conductivity plays a vital role in the conduction of heat from the component to all the area. The surface contact area of the cylinder was more compared to the cube as a result cooling rate in the cylinder was more which results in higher hardness.

### 3.2 Surface Roughness Analysis

Surface roughness is a surface texture of a material as it undergoes to erosion and friction. It was measured by the deviations from the real surface to textured surface. Rough surface was formed with large deviation occurs and if the deviation is less then smooth surface was formed. In general, higher wear rate takes place when the material was rough and smooth surfaces forms when the coefficient of friction was higher. Surface Roughness was also used to predict the performance of any component as irregularities on the surface of the material forms nucleation sites for cracks.

In this study, the surface roughness was measured from the average deviation from the regular surface. It was the average value of ordinates from mean line. The surface roughness for the two components is measured by a talysurf. The Talysurf was used to measure the surface roughness and surface texture of the material quickly and accurately. Talysurf shows the measured roughness ($R_z$) as well as the mean roughness value ($R_a$) in micro meters or microns ($\mu$m).
Figure 4. Mean Surface Roughness of casted shapes

In this study the surface roughness for the two components is measured by using portable surface roughness tester and the obtained values are plotted in graph as shown in Figure 4. The surface roughness graph showing the higher surface roughness observed at cube component with 0.415 Ra and lower surface roughness observed in cylinder with 0.325 Ra. At cube component the cooling rate was lower compared with the other component as a result it was prone to the coarse grains results in the softer surface. While the machining was done at higher cutting speeds and higher depth of cuts the surface of the cube component was becomes softer resulting high indentation on the surface with the deeper scratches resulting in the higher surface roughness. At the cylinder component it was showing the lower surface roughness as higher cooling rates were observed in the component, due to that finer grain structure was observed and resulting the lower surface roughness.

3.3 Wear Test
Wear test is a measure of the material erosion with time. It was used to predict the wear mechanism, wear property and amount of wear rate of any material. The major reason to perform the wear test was that whether the given material can withstand to resistance to wear.

From the Figure 5 it was clear that in both components cube and cylinder 600 rpm showing the higher wear rate and also cylinder component was showing the higher wear rate than the cube in both the rotation speeds of 600 rpm and 780 rpm. Here the interesting fact was, as the speed increases the wear rate should increase but interestingly lower rotational speeds showing the higher wear rate than the higher speeds the reason behind that was as the speed increases the friction generates in between the work piece and disc as a result heat generates which softens the material at the higher speeds which was lowering the wear rate of the component.

In both the components at both rotational speeds the wear rate was decreasing with the time. At starting after 100 seconds it was showing the peak wear rate after that as the time increases gradual decrease in the wear rate was observed. There are some fluctuations was observed in the wear rate as in few cases there was linear decrease and a non linear decrease in the wear rate can be observed in few cases. It was due to as the time increases the contact between the work piece with disc fluctuates as the work piece gets soften with the time and the softened material acts like a lubricant in between them due to that the contact between them fluctuates and which reduces the wear rate as the time increases.
4. Conclusions
This study is focused on the properties of AA2024 casted through silica sand. This study also focused on which shape yields better properties to the casting when silica sand is used as the moulding material. The following conclusions are drawn through this study:

1. Casting of both the components were successfully prepared without any defect and shape deviation through CO$_2$ casting process.
2. At cylinder component higher hardness was observed due to the faster cooling rate and lower surface roughness.
3. Wear test was conducted on the castings shows that cylinder was showing the lower wear rate and at 780 rpm rotational speed in both the cases showing the lower wear rate.
4. Out of those two components CO$_2$ process is better working for the cylinder type of objects.

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