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Reduction in Silica Sand Consumption by addition of fly ash Particles and its effect on Sand Mould and Aluminium Alloy 6061 Casting Properties

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Abstract

The global consumption of silica sand in the casting industries is increasing on a daily basis, which has not only increased the cost but also resulted in massive landfills, which have a negative impact on the environment. From the standpoints of availability, cost, and environmental protection, it has become necessary to replace silica sand, either partially or completely, with non-silica materials. To address this issue, the current research investigates the use of fly ash as a non-silica addition to silica sand. The proportion of fly ash in moulding sand was varied from 5% to 15%, and the effect on mould properties such as permeability, dry shear strength, and compression strength was investigated. The dry shear and compression strength of sand mould increased as the fly ash content increased. Furthermore, castings of aluminium alloy 6061 were made using a sand mould containing varying weight percentages of fly ash particles. Surface roughness, hardness, grain size, and tension tests were used to investigate the effect of fly ash content on the mechanical properties of aluminium alloy 6061 casting. The addition of fly ash particles to moulding sand was found to be beneficial, as the surface finish of the castings improved and the tensile properties improved.

Keywords: Fly ash;Moulding sand; Permeability; Aluminium alloys; Mechanical properties.

1.0 Introduction

Silica sand or industrial sand is used in many industries like casting, glass, abrasive material for sandblasting, production of building materials, porcelain production, oil and water filtration. If we according to a survey the global silica sand market by year 2021 was close to ~21.6 Billion dollar and it is expected to reach 30.9 Billion dollar by 2027.After glass industry (40% market share) it is foundry (20% market share) which uses silica sand as essential component in the production of ferrous and non-ferrous castings [1]. The mould and cores used for making castings are made using silica sand in combination with binding agent. There have been huge efforts to reduce the consumption of silica sand by using non-silica alternatives or reusing the waste sand. This is mainly because sand extraction and processing results in loss of soil, loss of wildlife habitat and emission of air pollutants. For instance during extraction and processing of 1 kg of silica sand about ~120 g of CO_2 is released [2]. The foundry men working in foundries do suffer from certain diseases from the dust and silica contaminated air [3].Although ventilation system did provide some solution cannot eliminate the air-borne free silica and for that it has become necessary to substitute the sand with other reliable material. Further large consumption of silica sand in foundries has led to generation of million tonnes of waste sand in which about 75% is landfilled. If we according to a thumb rule then the amount of waste sand generated after casting process almost similar to that of casting produced. This discarded waste sand contains microscopic traces of many impurities which can cause environmental contamination. For example the foundries which are into brasses casting showed lead rich nodules on moulding sand surface [4]. These nodules of lead later react with the clay in the moulding sand to form Pb-Al silicates which increase the toxicity of waste sand. These are some major concerns related to use of silica sand in the foundry and need attention.

Many efforts have been undertaken to replace the silica sand with non-silica based alternatives such as coconut shell powder, ferrochrome slag, groundnut shell ash, blast furnace slag, red mud, anthill powder, tamarind powder and fly ash particles. The research work in most of these substitute materials is in preliminary stage and constant efforts still underway. In a comprehensive review, Sadarang et al [5] provided details on different alternative materials which could be used for making sand castings. Addition of different combination of these alternative materials and their influence on permeability, green and dry compressive strength was presented. Further effect of these materials on freezing temperature of casting was also provided to understand how they influence the grain structure and mechanical properties. Karunakaran et al [6] utilized fly ash particles obtained from sugar industry as an additive to the mould sand for making aluminium castings. The weight percentage of fly ash was varied from 0 to 52% and out of all the mould sand with 24% fly ash was able to produce castings with acceptable surface finish. Rao and Murthy [7] reported comparative analysis of mould made up of granulated blast furnace slag and silica sand. The mould property such as mould hardness of furnace slag was on par with the silica sand and the castings showed good surface finish and dimensional

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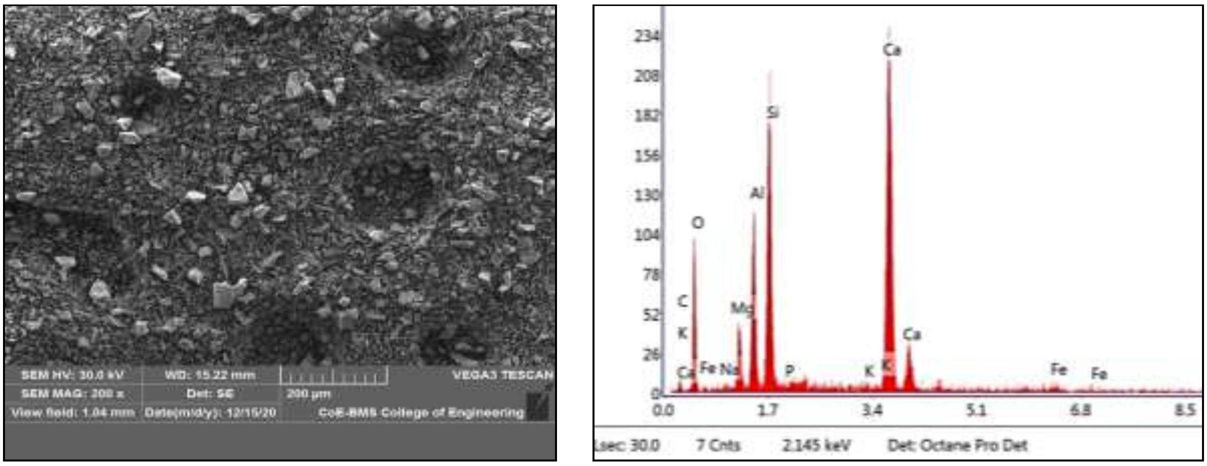
accuracy. Okonji et al [8] conducted a feasibility studies to employ groundnut shell ash and ant hill powder in mould sand. Out of different combination, the one with 14% groundnut shell ash and 30% ant hill powder in silica sand was found to be feasible to produce non-ferrous castings. On the other hand, fly ash which is produced as by-product during combustion of pulverized coal has emerged as potential engineering material in past two decades. The fly ash is extensively used in civil engineering and construction applications like road bases, structural fills, pavement sub sealing, highway construction and pavements [9]. Fly ash has also been used as reinforcement for aluminium and magnesium alloy matrices to improve their mechanical and corrosion properties. The fly ash particles were added to polymer matrices and their effect on various properties was analysed. In most of the fly ash reinforced composites the mechanical and tribological performance was found to improve [10]. In a nutshell this work is focussed on employing fly ash as non-silica additive to the moulding sand. Since it is industrial by-product and available at low cost with good physical properties making it a suitable candidate material for mould sand additives. The basic properties of fly ash included moulding sand such as permeability, shear and green strength were studied. Further effect of fly ash content in moulding sand on microstructure and mechanical properties of aluminium alloy 6061 castings was studied.

2.0 Experimentation

In this work fly ash particles procured from local power plant having average particle size 20-60 microns was used as additive to moulding sand. The procured fly ash particles were subjected to scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS)tests to study morphology and chemical composition. The thermo-gravimetric analysis (TGA) of fly ash particles was carried out to understand the thermal behaviour. The weight percentage of fly ash in the moulding sand was varied from 0 to 15% in the step of 5%. The moulding sand was prepared by mixing silica sand, fly ash, bentonite and water using sand muller. The mixed sand was than rammed using sand rammer. The moulding sand was subjected to green permeability, dry shear and dry compression strength tests by following American Foundry Society (AFS) standards. The reading presented here is an average value of three sample readings. The mould sand prepared with different combination of fly ash content is used for making 6061Al alloy castings. The ingots of 6061Al alloy was placed in a graphite mould and melted using a temperature of 800°C. Once the melting was concluded the degassing of molten metal was carried using hexachloroethane tablets. After degassing the molten metal was poured into different mould and allowed to cool to room temperature. The castings of 6061Al alloy were subjected to surface roughness test to understand the surface finish. The microstructure and grain size analysis was obtained using optical microscope with image analyzer (Make: OLYMPUS Microscope and Clemex Image Analyser) by following ASTM E112-96. The Vickers microhardness test was conducted on polished samples of casting by applying a load of 100 grams and dwell time of 10 seconds. About three indentations were made on each sample and average value is reported here. The tensile properties of castings were obtained by subjecting them to tension test on samples prepared as per ASTM E8 standard.

3.0 Results and discussion

The SEM micrograph and EDS of procured fly ash particles are shown in Fig. 1 (a) and (b). It can be seen that fly ash had spherical morphology with average particle size of 40 µm. The EDS as presented in Fig. 1 (b) shows large peaks corresponding to Ca, Si, O, Al, Mg elements which correspond to SiO_2, Al_2O_3, MgO and CaO, the main constituents of fly ash particles. The other elements seen here are Fe and K which could be related to Fe_2O_3 and K_2O, the other constituents of fly ash. The TG analysis of fly ash particles is shown in Fig. 2and a major variation is observed in the temperature range of 350°C to 750°C. In this temperature range the mass loss seen is due to removal of chemical bonds of water molecules and decomposition of $CaCO_3$. Similar observations were made by Rajamma et al [11] on their work on TGA analysis of biomass fly ash. The authors found decomposition of organic matter and $CaCO_3$ at 300-600°C and 800°C respectively.



(a) (b)

Fig. 1 (a) SEM micrograph and (b) EDAX pattern of fly ash particles

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3.1 Mould properties

The mould property with varying fly ash content is provided in Table 1. These properties would provide an idea on how mould will dictate the casting surface finish and strength. Permeability is an important property of sand mould which provides an insight on how well the mould can vent the gases through it.

When the molten metal is poured into the mould it rapidly heats its surface and boils off the moisture or other volatile compounds. However there are certain chances that the moisture might migrate to cooler and deeper part of the mould. With advancing molten metal the moisture evaporates again and migrates further or removed from the mould if appropriate permeability is maintained. If not then there are high chances of very dry and superheated steam getting entrapped in the mould and produce oxide on the surface of casting. These entrapped gases could either cause blowing of metal or impeding the flow of metal into the mould. In general the moulding mixture must have permeability number in between 20 to 40to obtain defect free aluminium alloy casting. As per table 1, the permeability number is in the range of 64.7 to 45.8 for different fly ash content in the moulding sand. This implies that the moulding sand with highest fly ash content of 15% is more porous than that of moulding sand which contains 5% fly ash content. Although higher permeability number facilitates better amount venting of steam generated or entrapped gases but it also causes formation of penetration type defects. However low permeability number is not recommended because the gases are not allowed to escape outside and they remain in mould causing defects like surface blow hole, gas or pin holes.

In a similar work, Munusamy et al [12] studied the effect of fly ash on permeability of green sand. With the increase in fly ash content from 0% to 16%, the permeability of sand was found to decrease. The dry shear and compression strength of sand mould was studied and the results are tabulated in Table 1. It can be seen that with the increase in fly ash content, both dry shear and compression strength tend to increase. For sand mould with 15%fly ash content, the highest dry shear and compression strength obtained were 186 gm/cm^2 and 352 gm/cm^2 respectively. The increase in strength values can be attributed to good interlocking between the sand as well as fly ash particles. The sand and fly ash particles are angular and spherical in morphology which might have resulted good interlocking. Along with the addition of binder the interlocking was furthermore strengthened which led to higher mould strength values for mould sand which had higher fly ash particle content. This is well reflected in the permeability number as it decreases with the increase in fly ash content and had a low value of 45.8 for sand mould with 15%fly ash content. In a similar work, Murthy and Rao [13] reported increase in dry shear and compression strength with the increase in Fe-Cr slag content. The enhanced mould strength was attributed to better bonding between particles due to addition of sodium silicate binder.

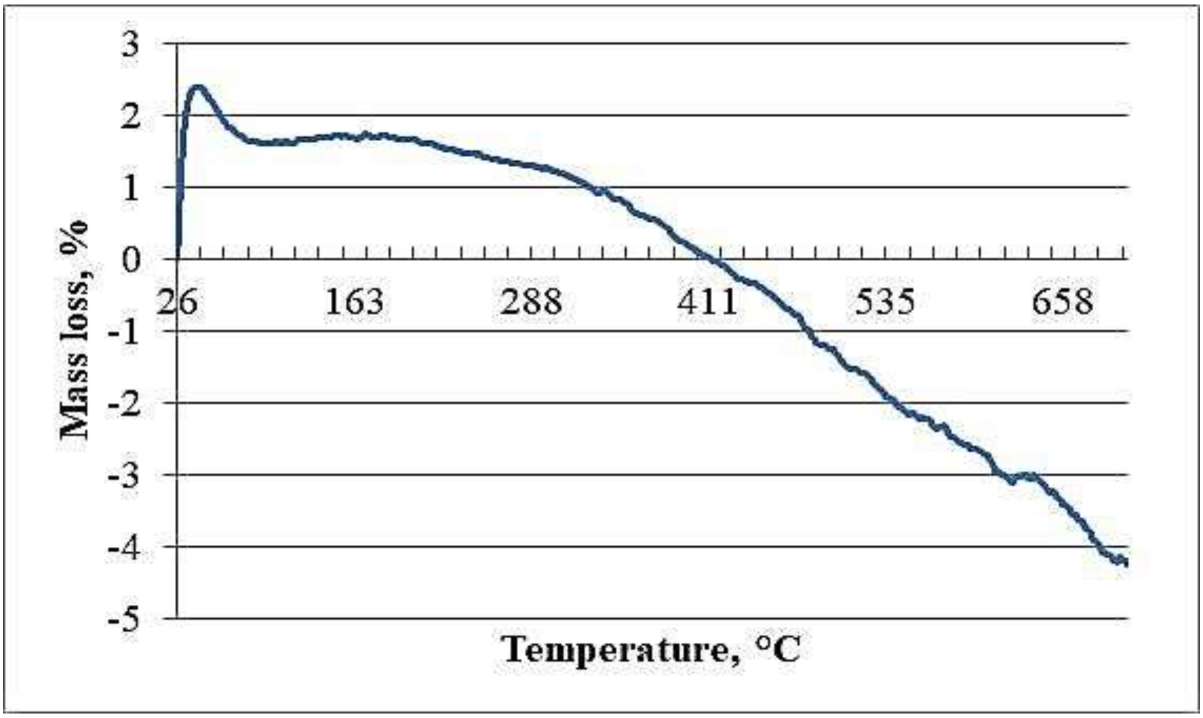
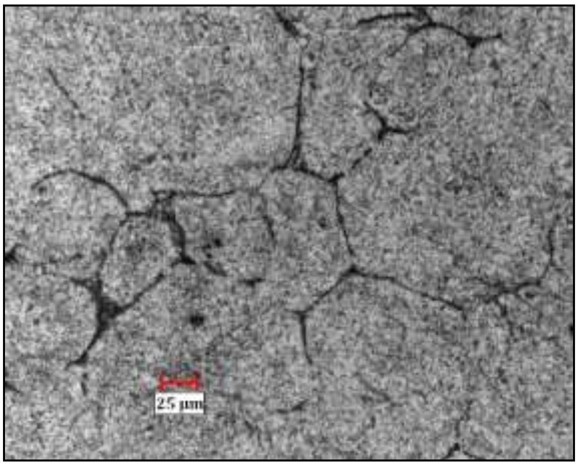
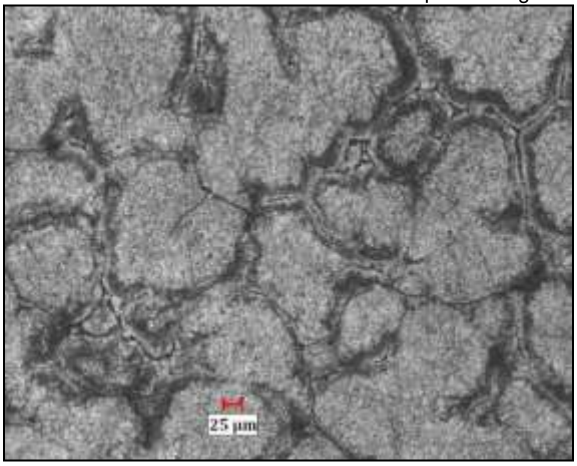


Fig. 2 TGA analysis of fly ash particles



(a) 5% fly ash



(b) 10% fly ash

Fig. 3 Optical micrographs of aluminium alloy 6061 castings prepared in mould sand with fly ash content

Table 1

Mould properties with different fly ash content

	Wt% in sand	Permeability	Shear Strength (gm/cm^2)	Compression Strength (gm/cm^2)
Fly ash	5	64.7	141	321
	10	58.77	174	333
	15	45.8	186	352

Table 2

Casting properties when fabricated in sand mould with different fly ash content

	Wt% in sand	Grain size (Microns)	Surface Roughness (Ra)	Vickers Hardness	Yield strength, MPa	Ultimate tensile strength, MPa
Flyash	5	62	3.7	59	75	153
	10	60	3.9	62	86	168
	15	57	4.1	68	88	179

3.2 Casting properties

The microstructure analysis of 6061Al alloy castings prepared in sand mould with different amount of fly ash content is shown in Fig. 3 (a) and (b). Both the micrographs showed dendritic structure corresponding to α-Al with eutectic phase seen in between the dendrites. However the size of dendrites is quite smaller in case of sand mould having 15% fly ash content as compared to sand mould having 5% fly ash content. In case of sand mould the rate of freezing is controlled by the mould itself and its ability to absorb heat. The probable reason in present case could be addition of fly ash to the sand mould which facilitates faster heat transfer.

The fly ash is well known for better heat transfer capability and is added to many materials or media to enhance the heat transfer capability [14,15]. The refinement in grain size is quite beneficial from mechanical properties point of view as small grains favor increment in strength. However in order to quantify the grain size, the analysis as per ASTM E112-96 was conducted and obtained average grain diameter is presented in Table 2. It can be seen that the obtained values do support the microstructural evidences presented in Fig. 3. With increase in fly ash content, the average grain diameter was found to decrease from 62 µm to 57 µm. Although the extent of grain refinement is not high but considerable decrease in average grain diameter is observed. The fast heat transfer in sand mould having 15% fly ash content causes rapid solidification of molten 6061Al alloy which facilitates in the formation of small and equi-axed grains. Higher the cooling rate higher will be the nucleation rate thereby resulting in grain refinement. Further the high cooling rate doesn't give enough time for grain to grow and the smaller grain try to remain intact [16].On the other hand coarse grains are formed due to slow solidification in the sand mould having 5% fly ash content.The heat transfer in this sand mould is considerably lower due to which the molten metal solidifies slowly and is maintained at relatively higher temperature. The slow cooling rate promotes grain growth due to suppression of nucleation and formation of coarse grain structure in the alloy. The surface roughness of 6061Al alloy castings is presented in the Table 2 and it is seen that the Ra value varies from 3.7 to 4.1. From permeability point of view the roughness values are showing quite different trend which is generally seen in the literature [17]. In general if the mould has high permeability then it tends to produce rough castings while one having low permeability results in low surface finish. In present case the trend is quite different as the mould with low permeability produced casting with high surface finish. From this observation it is quite clear that the surface roughness is not solely dependent on the permeability but other parameters like particle of silica sand, ramming pressure and curing temperature should be considered.

The mechanical properties such hardness, yield and ultimate tensile strength of 6061Al alloy castings as function of fly ash content in sand mould are presented in Table 2. All the three properties were found to increase with the fly ash content and showed highest value at 15%. The hardness, yield and ultimate tensile strength of 6061Al alloy casting were found to have highest value of 68 VHN, 88 MPa and 179 MPa respectively for 15% fly ash content. When compared to 5% fly ash content, the increment in these properties is about 15.25%, 17.34% and 17% respectively. The increment in the mechanical properties is quite good and is attributed to grain refinement in the 6061Al alloy castings. From average grain diameter values it is quite clear that the lowest grain size was obtained for sand mould having 15% fly ash content. According to Hall-Petch relationship which states that the hardness or strength is increased if the grain size of material is decreased [18-20]. As the grain size decreases the number of grain boundaries increases due to which the dislocation mobility is greatly restricted. Here the average grain diameter of sand mould having 15% fly ash content is quite less that of sand mould having 5% fly ash content. From this point of view it is quite clear that as the grain size is decreasing the mechanical properties are increasing. Further the grain refinement reduces the extent of formation of casting defects such as porosity and segregation. With less number of casting defects the strength exhibited will be on higher side than those castings which have casting defects. This implies that the sand mould having 15% fly ash content has less number of casting defects which is probably due to grain refinement and due to this the casting made from this mould has highest mechanical properties.

4.0 Conclusions

In this work the silica sand consumption in making sand mould was achieved by using fly ash as additive material. The weight percentage of fly ash in mould sand was varied from 5% to 15% and its effect on mould and sand properties were studied. The conclusions obtained from this work are as follows,

- With increase in fly ash content, the sand mould showed decrease in permeability but increase in dry compression and shear strengths.
- The increase in strength of sand mould is attributed to better interlocking between silica sand, fly ash and binding agent.
- The microstructure and grain size analysis showed increase in grain refinement as the fly ash content in sand mould is increased to 15%.
- The highest hardness, yield and ultimate tensile strength of 6061Al alloy casting were found to have value of 68 VHN, 88 MPa and 179 MPa respectively for sand mould with 15% fly ash content.
- The increase in mechanical properties is attributed to grain refinement caused by better heat transfer and quick solidification when the fly ash content in the sand mould was 15%.

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