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Investigating the Effect of Counter Gravity Mold Filling on Microstructure and Mechanical Properties of Cast Aluminium

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Abstract
In present study an effort has been made to investigate the effect of changing the mode of mold cavity filling on mechanical properties and microstructure of cast aluminium. The pouring of the melt in mold cavity is avoided so as to check defects associated with it and instead of pouring, counter gravity filling of mold technique is utilized. The obtained properties and microstructure are compared with gravity poured (traditionally cast) aluminium. Characterization techniques like optical microscopy, scanning electron microscopy, X-Ray diffraction and mechanical testing like tensile and hardness of the cast samples is carried out. Hardness and tensile strength reported an increment of 22.37% and 26.71% respectively as compared to traditionally cast specimens. This enhancement in mechanical properties was attributed to improved microstructure obtained.

Keywords- Aluminium casting, Casting defects, Counter gravity casting, Mold filling.

1. Introduction
The demand of high strength to weight ratio materials in aerospace, automobile and other engineering applications has attracted researchers towards aluminium and its alloys (Davis, 1993). They offer several superior properties such as low weight, high strength, corrosion resistant, formability and machining (Surappa and Rohatgi, 1981). Aluminium alloys are among the most preferred materials used as base matrix in composites (Hashim et al., 2001). Several processes are used to manufacture aluminium components but casting is proved as most suitable process due to its ability to produce complex and intricate geometries and economy (Schleg and Kanicki, 2000). Campbell (2004) stated that aluminium casting through gravity pouring (traditional method) is considered as a challenging task due to the occurrence of defects like porosity and shrinkage and other defects due to turbulence. Pouring of molten metal in cavity is considered as a prime factor causing these defects and hence the quality of the final products in terms of its microstructure and properties are compromised, therefore, the cause of these defects needs to be addressed (Campbell, 2012). Counter gravity filling of mold during casting can eliminate these defects to a large extent (Li et al., 2008). Therefore a method needs to be adopted

that involves the mold filling during casting in a different manner as used by low pressure die casting (Bonollo et al., 2005; Liu et al., 2018, and Reilly et al., 2013) and counter gravity casting (Aremo and Adeoye, 2011). These techniques does not involve pouring instead allow the molten metal to enter in cavity through bottom portion (Yan et al., 2010). The melt from bottom most part of molten metal enters inside the cavity to avoid any defects and entrapment of inclusions. In molten metal, most of the impurities floats on the surface and when these impurities enter in the mold cavity along with the molten metal during pouring, affect the quality of the casting produced.

In present work, a novel method has been adopted to produce casting in which pouring of the melt is avoided so as to check defects associated with it. Instead of pouring, counter gravity filling of mold technique has been utilised and its effect on the microstructure and mechanical properties of final cast is studied. The obtained properties and microstructure are compared with gravity poured (traditionally cast) aluminium samples.

2. Materials and Method

The Principle utilized (counter gravity filling of mold) during the experiments is illustrated in Figure 1. As can be seen a graphite crucible is used for melting the metal, a hollow sprue is dipped in molten metal with its one end connected to mold cavity, a circular disc is placed on the surface of melt and is connected to rack and pinion arrangement for its up and down motion in order to apply force on the surface of melt.

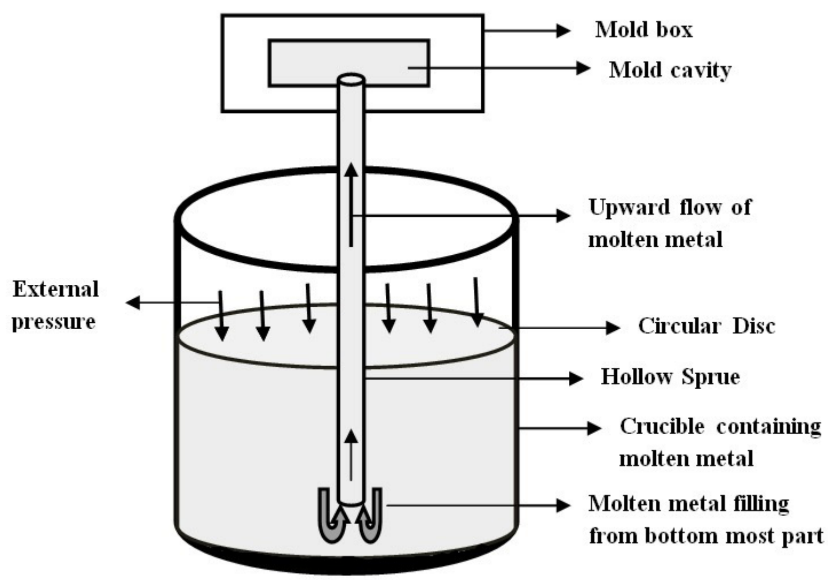

Figure 1. Schematic view of the process

Based on the literature survey, avoiding pouring of melt in mold cavity eliminates casting defects like voids, inclusions and defects due to the turbulence of gravity poured metal. Hence an attempt has been made to utilize the concept of LPDC and counter gravity casting, so as to fill mold cavity with cleanest possible melt and to study the influence of this filling technique of mold during casting, on the mechanical properties and microstructure of produced aluminium casting.

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Aluminium and its alloys are considered as high strength materials and second most used after steel. Pure aluminium, when mixed with several other elements, results in several aluminium alloys and is designated by different numbering systems. In present work, commercially available pure aluminium (>99% purity) was utilized. The experimental set for performing the casting trials was designed by combining the different parts or items as shown in Figure 2. A graphite crucible having diameter 100 mm and 170 mm height was used to melt the aluminium. Sprue with diameters of 7 mm and 8 mm were designed and manufactured after machining an EN grade steel rod in order to fill the molten metal in the mold cavity. The rack and disc arrangement was used for downward movement of the disc in the graphite crucible and simultaneously applying pressure on the molten metal. The downward motion of the disc was powered by an induction motor with 1400 rpm, connected with pinion. The RPM of the motor was controlled using a speed regulator. The induction motor was fitted on the wooden table for height adjustment. All the experimental trials were carried out on the same experimental set up.

Figure 2. Components used in designing the experimental set up, crucible, sprue, rack and pinion, induction motor, table for height adjustment and bracket for supporting rack

All the above components were assembled to make a complete set up as illustrated in Figure 3 for carrying out the experiments

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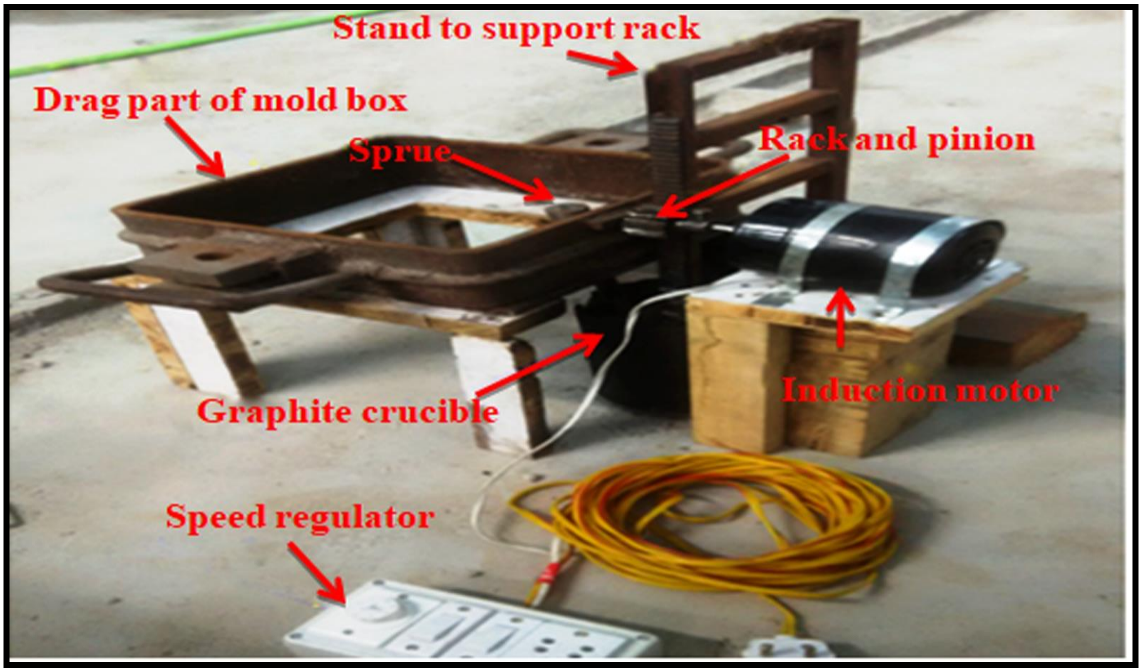

Figure 3. Experimental set up used for the experiments

A graphite crucible was used for melting the aluminium (above 700̊ C) in induction furnace. External pressure was applied on the upper surface of superheated aluminium melt with the help of stainless steel (EN 19 grade) disc, connected to rack and pinion arrangement for upward and downward movement of the disc. The pinion was given rotary motion with the help of an electrical motor. The downward movement of the disc applied pressure on the top surface of the molten aluminium and the melt is forced to move through the hollow sprue of diameter of 4, 5, 7 and 8 mm respectively (separately), placed in the molten aluminium. The other end of the sprue is connected or placed in the cylindrically shaped sand mold cavity. The melt was degassed with degassing flux hexachloroethane (C_2Cl_6) to check the hydrogen entrapment and the disc was preheated to avoid any chilling etc. The molten metal from the bottom portion is forced to fill the mold cavity. The filled cavity was allowed to solidify, and the desired aluminium cast samples were produced. With sprue diameter of 4mm, proper filling of cavity was not achieved, may be due to very less amount of metal moved to the cavity. Hence effort was made with higher sprue diameter Therefore, testing of samples produced with sprue diameter 7 and 8 mm is carried out.

3. Results and Discussions

Cast samples from each experimental trial was subjected to tensile and hardness testing. The sample for testing were prepared from the cast specimens following grinding, polishing and further etching (Keller's reagent) was done for carrying out metallurgical characterization. Techniques like SEM (scanning electron microscopy), XRD (x-ray diffraction) and OM (optical microscopy) were used to study microstructure and flow pattern of the melt in the prepared specimens.

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3.1 Optical Microscopy
The optical micrographs of cast specimens produced via counter gravity filling technique with sprue diameter 7 mm and 8 mm are shown in Figure 4. The proposed counter gravity filling technique have an influential role in the reduction of inclusion and pores as only the cleanest metal has entered in the mold cavity. With further increase in sprue diameter from 7 mm to 8 mm, pore and inclusion defects were reported to be almost eliminated due to more uniform flow of molten metal in the cavity and improved microstructure is reported.

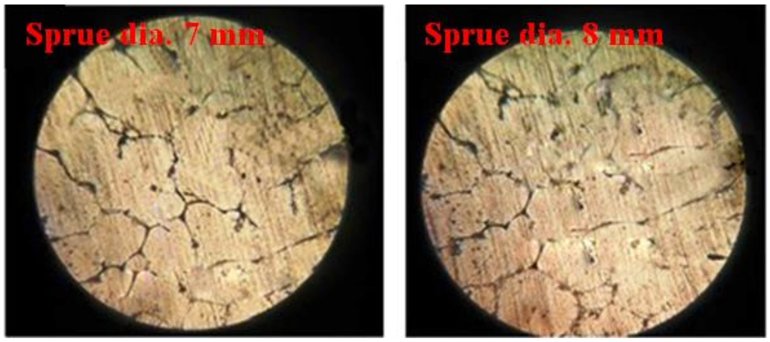

Figure 4. Optical images of counter gravity cast samples

3.2 Scanning Electron Microscopy
SEM morphology of traditionally cast (gravity poured) sample can be seen in Figure 5. Presence of inclusions and pores can be seen in microstructure of gravity cast aluminium. Their presence may be attributed due to entrapment of hydrogen and turbulence during the poring of molten metal in to the cavity

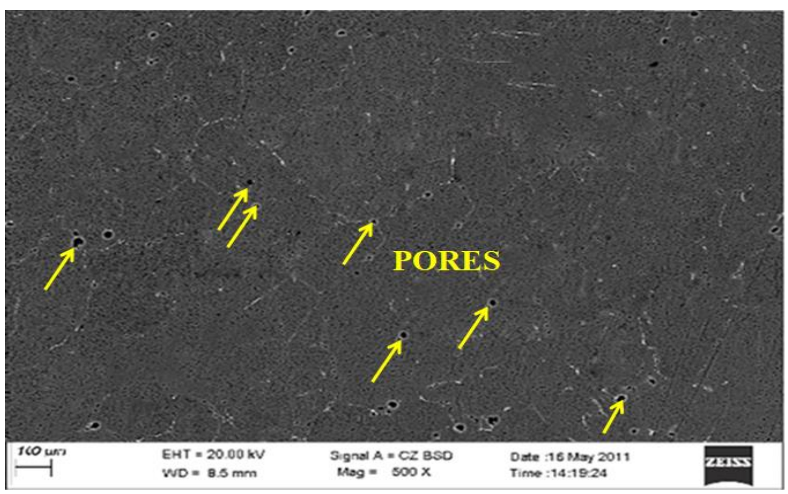

Figure 5. SEM image of traditionally cast sample

Figure 6 shows the SEM image of counter gravity cast sample using 7 mm sprue diameter. A very few micro pores and inclusions are observed as compared to gravity poured samples. The same may be achieved due to absence of turbulence (sand erosion etc.) due to pouring and uniform filling of mold. Here porosity, density of pores and pore size are significant decreased. This shows that hydrogen gas entrapment and inclusions are greatly reduced with the adoption of

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counter gravity filling of mold technique as this technique allows the cleanest possible metal in the mold cavity.

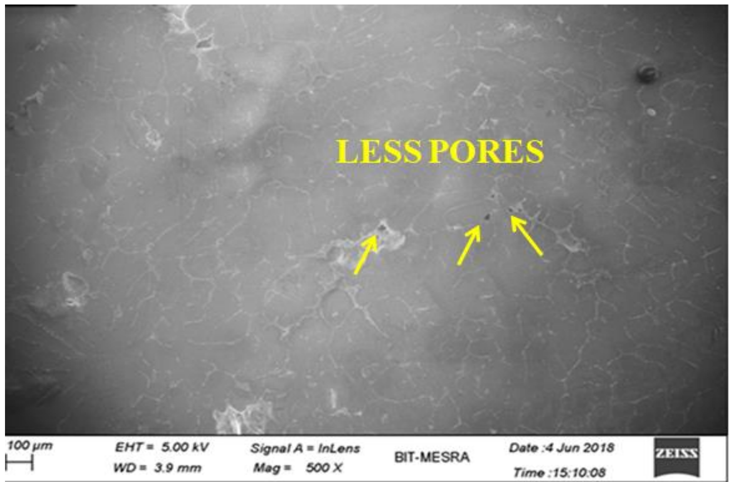

Figure 6. SEM image of sample cast by counter gravity process with 7 mm sprue diameter

Figure 7 shows the SEM image of aluminium sample cast with sprue diameter 8 mm, it has been observed that micro pore and inclusion defect are almost eliminated in the sample, with higher sprue diameter as the molten metal fills the entire mold cavity in more controlled manner. Thus, due to controlled filling of mold cavity, defect free casting is obtained and there is significant increase in the mechanical properties of the cast sample as discussed above.

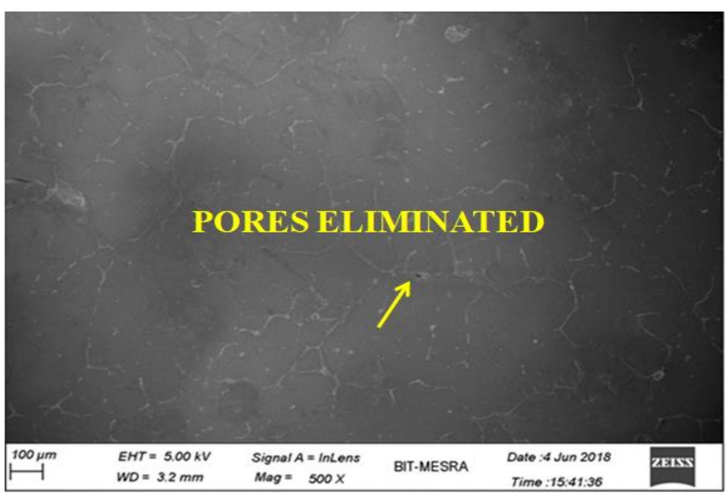

Figure 7. SEM image of sample cast by counter gravity process with 8 mm sprue diameter

3.3 X-Ray Diffraction

Figure 8 shows the X-Ray Diffraction pattern of the cast sample developed using counter gravity filling of mold with sprue diameter 8 mm. All characteristic peaks of aluminium were matched using the reference data. In the present figure (h, k, l) values of (111) (200) (220) & (311) corresponds to the aluminium phase. Diffraction peaks correspond to the aluminium phases were observed in the sample. Therefore, it can be concluded from XRD studies that no other inter metallic compounds are present; the same may be resulted to the absence of any foreign particle (inclusions etc.)

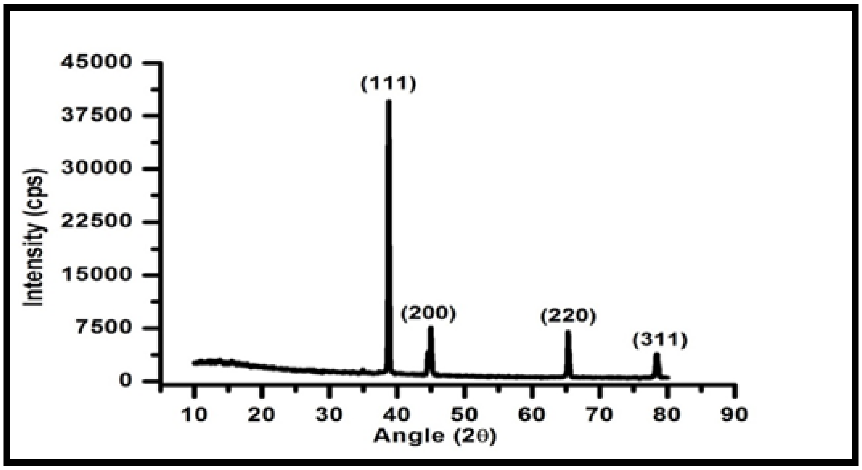

Figure 8. XRD pattern of cast samples with sprue diameter 8 mm

3.4 Ultimate Tensile Strength (UTS)

Tensile testing of aluminium castings produced with the proposed counter gravity mold filling method was conducted on UTM machine (Model INSTRON) and the obtained results were compared with gravity poured cast samples. The tensile test specimens were prepared as per ASTM E8 standard as shown in Figure 9.

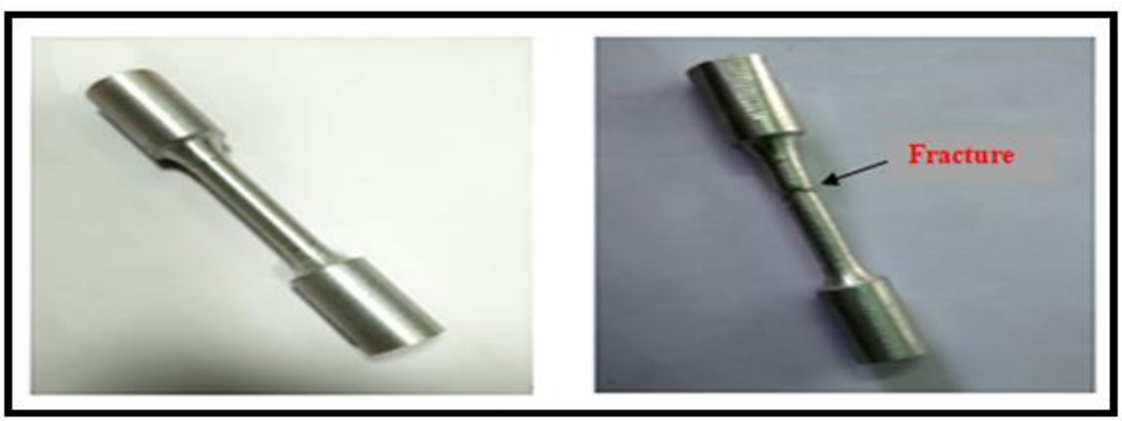

Figure 9. Tensile specimen before and after testing

Figure 10 shows stress strain curves for counter gravity cast specimens developed using sprue of diameter 7 mm and 8 mm. The UTS has attained a considerable increment and the strengthening may be concluded due to reduction in dislocation site as a result of reduced pores density and pores size. The obtained values of tensile strength for different samples are presented in Table 1

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Table 1. Ultimate tensile strength of cast samples

Casting method	UTS (MPa)
Traditional pouring	97.2
counter gravity filled (sprue diameter 7 mm)	110.30
counter gravity filled (sprue diameter 8 mm)	123.17

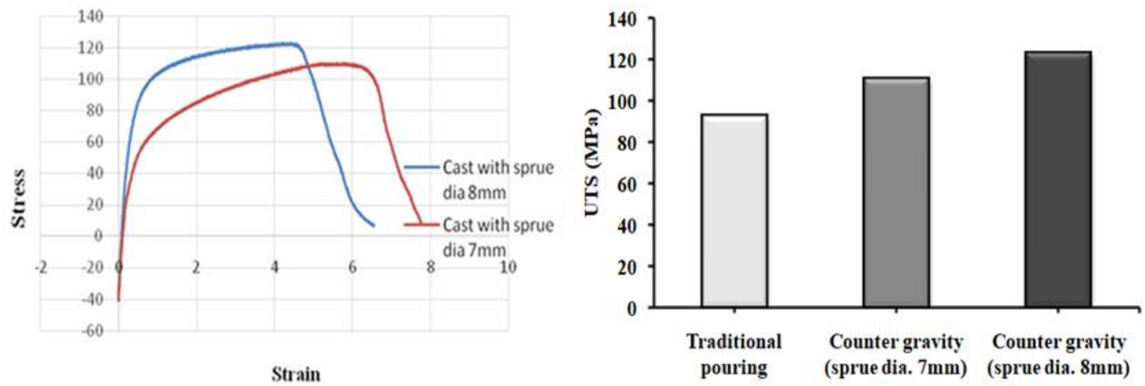

Figure 10. Stress strain curves and UTS of cast specimens

The UTS for counter gravity filled casting with 8 mm diameter is on higher side by 26.71% as compared to gravity poured cast sample. Further, it was also reported that sprue diameter has an influential role on the tensile strength. The strength was increased by 11.67% for sample cast with sprue diameter 8 mm as compared to samples cast with sprue diameter 7 mm. This increment may be attributed to even material flow that leads to proper filling of the cavity. The yield strength of the cast specimen as obtained from stress strain curves and plotted in Figure 11. The yield strength reportedly increased with increase in sprue diameter as a result of improvement in microstructure with reduction in pores.

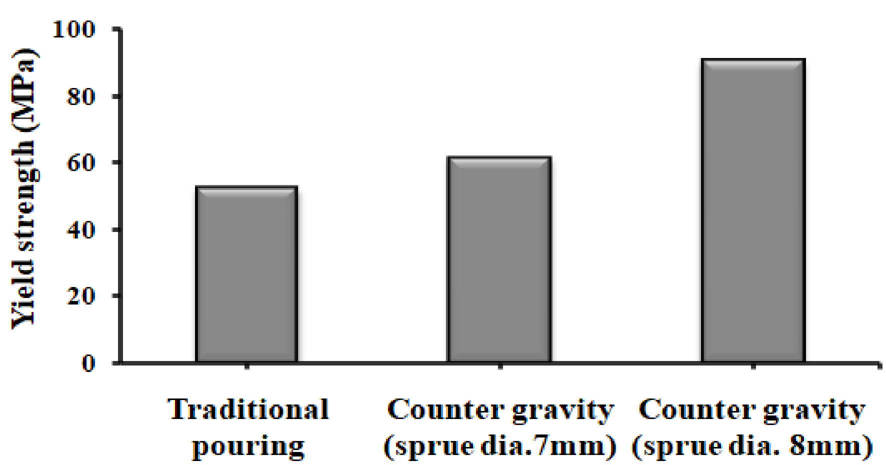

Figure 11. Yield strength of cast specimens

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3.5 Hardness
The hardness testing was performed using Brinell Hardness Tester. Three indentations were made on cast samples using 10 mm diameter ball and average hardness values obtained are reported and plotted in Table 2 and Figure 12 respectively.

Table 2. Hardness of samples

Casting method	Average Hardness (BHN)
Traditional pouring	27.8
Counter gravity filling (sprue diameter 7 mm)	31.8
Counter gravity filling (sprue diameter 8 mm)	34.02

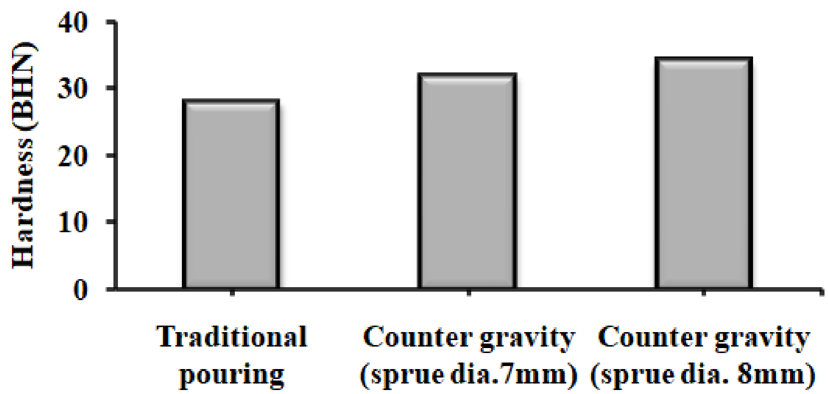

Figure 12. Hardness of fabricated samples

The hardness obtained for sample with sprue diameter 7 mm is found to be increased by 14.38% as compared to traditionally cast samples; the same was concluded due to the reduction in porosity and pinholes also confirmed by SEM and OM analysis. With increment in sprue diameter from 7 mm to 8 mm, the hardness is increased by approx.

4. Conclusions
In present study we have investigated the effect of changing the mode of mold filling on the mechanical and metallurgical behavior of aluminium castings. The proposed mold filling technique have positive influence on microstructure as the voids, porosities are eliminated to great extent. This improvement in microstructure has lead to increase in tensile and hardness of cast samples. An increase of 26.71% in ultimate tensile strength and 22.37% in hardness is reported. High material yield is achieved as the proposed technique has eliminated the need of riser.

Conflict of Interest
The authors confirm that there is no conflict of interest to declare for this publication.

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