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Comparison of Tensile Properties of Nb Grain Refined A206 Alloy by Gravity and Tilt Casting

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Abstract

Turbulent filling of a mould is one of the ways to introduce extrinsic defects into the cast part that could deteriorate many properties of any casting. The turbulence can be easily eliminated by counter gravity casting. In gravity casting, tapered downsprue, tapered runner is needed such that the mould cavity is filled counter-gravity from the bottom which is the only best way to eliminate turbulence during filling. Tilt casting method also exists which has the potential to quiescently transfer the liquid into the mould cavity. In this work, gravity and tilt casting methods were used to evaluate the tensile properties of Nb grain refined 206 alloy. Three different Nb contents were investigated: 0.025, 0.05 and 0.1 wt% ratios and it was found that 0.05 wt% revealed the highest tensile properties. On the other hand, when the intrusion of surface folded oxides was eliminated during filling, it was found that mechanical properties were increased significantly, and particularly, the toughness was increased by two folds when tilt casting was applied compared to gravity casting.

Keywords: A206, Aluminum, Tilt casting, Tensile properties, Toughness

1. Introduction

When the liquid metal is poured into the mould cavity towards gravity, it has the potential to generate turbulence. This results in entrainment of air bubbles that deteriorate the properties of castings such as porosity. It is well-known that there is a critical velocity for liquid metals above which turbulence occurs [1–5]. Mirak [6] studied the effect of ingate velocities on the mechanical properties of Al and Mg alloys. Weibull statistics were used to interpret the tensile test results. It was reported that 0.4 m/s and 0.25 m/s was the limit for Al and Mg alloys respectively based on the Weibull modulus. Above these values, Al_2O_3 and MgO oxides were detected on the fracture surface of tensile samples which revealed that turbulence had occurred during filling.

Since the surface of the liquid aluminum oxidizes rapidly, in such actions, oxides are also introduced into mould cavity resulting in rejection of the cast part. To eliminate the formation of these defects, the quiescent filling of the mould cavity is needed. Particularly, in the case of gravity castings, optimized runner and sprue design is inevitable. Therefore, a tapered down sprue, followed by tapered runner which then follows an ingate to fill the cavity counter-gravity is essential. This is also known as bottom-gating systems where more reliable cast parts can be produced [6–9].

Hsu [10–16] made an extensive work on the design of runner systems and their effect on the casting quality. Ahmad [17, 18] reported that the size of vortex runner gating system was found to have an effect on the flexure strength of Al-12Si alloy castings. The results showed that the increment of mechanical strength of Al-

12Si alloy castings was directly proportional with increment of runner diameter size. Majidi [19] pointed out to the fact that when tangential gating system is used which is the natural geometry of the falling liquid, air entrapment during filling was significantly reduced. El Sayed [20, 21] showed that use of filtration would control the melt flow in the mould cavity to result in increased tensile properties due to absence of oxide defects. Jezierski [22] studied different gating systems using simulation tools to investigate the re-oxidation of liquid meniscus flowing in the mould cavity. It was reported that trident gates, spin trap, and bubble trap was needed for quiescent filling of the mould for large and heavy castings. Filling systems molded to follow the shape of the falling stream (particularly the naturally pressured system) are successful to reduce the conditions for forming entrainment defects [23]. Remisova [24] reported that by correct design of the gating system, quiescent filling was achieved. Haidong [25] used simulation and experimental work to validate the proposed model. X-ray results were compared with simulation and it was reported that the model could predict the mould filling.

It was in 1913, Durville [26] had patented the tilt casting method which led to the studies on roll-over casting and low-pressure counter-gravity castings. Pease [27] pointed out that tilt casting can naturally minimize surface turbulence but yet have not received the full attention in casting operations. Pavlak [28] looked into the effect of top casting, bottom gating and tilt casting on the quality of aluminum cylinder heads. It was reported that leaking defects were eliminated by smooth and quiescent filling.

Cox [29] compared gravity and rotating tilt casting of Al7Si0.4Mg alloy. Used real-time X-ray to evaluate mould filling. Weibull statistics were used, and the lowest Weibull modulus was recorded for the gravity casting whereas tilt casting had twice the higher modulus value. Several tilting speeds were investigated. It was reported that fast tilting had resulted in filling of thin sections, but slower tilting resulted in more reliable castings. Hamza [30] used Al11Si alloy where a die cavity was filled at different angles. As the tilt angle was increased, tensile properties had increased however after 3 degrees, the properties were decreased, yet, still higher than the gravity casting. It was also reported that cooling rate of the die was decreased with increased tilt angle which resulted in coarser grain size. Gokhale [31] reported that various size and shapes of oxides were observed on the fracture of tensile samples cast by tilt pouring method. There was no detailed information about the melt treatment and gating systems, but it very likely that these defects were coming from the melt, or the tilting operation was fast. Sigworth [32] showed that tilting rate is the key parameter for achieving low scrap rates in casting of Al-4Cu alloys. Mi [33] proposed that starting from zero angle degree (horizontal), then tilting the mould might led to increased velocities during filling which could exceed critical velocity. On the other hand, a maximum of 10º tilt as the starting point was proposed as the upper limit because above which less reliable castings were produced. Ransing [34] used simulation to evaluate the tilting speed and the results were compared with experimental data in the literature. It was suggested that tilting should not start horizontally but should be limited to max of 16 degrees for viscous flow without turbulence.

There are several studies on the grain refinement of aluminum cast alloys with Nb [35-39]. Particularly, in the presence of B, NbB_2 and $NbAl_3$ are found to be the effective nucleating sites for primary dendrites. Various ratios of Nb/B were studied, and it was reported that 10/1 was the optimum effective ratio [40].

2. Materials and Methods

In this work, A206 alloy was used, and the chemical composition is given in Table 1.

Table 1.
Composition of A206 alloy

Cu	Fe	Si	Mn	Mg	Ti	Al
4.79	0.12	0.14	0.36	0.23	0.25	Bal

15 kg base alloy was melted in SiC crucible in induction furnace (ICS). The casting temperature was selected as 770 ºC. Nb addition was made by Al3Nb0.5B master alloy to achieve 0.025, 0.05 and 0.1 wt% in the alloy. Sand moulds were used in the tests with 60 AFS sand, 2 wt% resin and 0.5 wt% hardener. Tensile samples were produced where 10 cylindrical bars were cast with the dimension of Ø8 by 160 mm. Two different casting method was used: (i) gravity pouring (Figure 1a), and (ii) tilt casting (Figure 1b). Tilt casting starting angle was 20º, as the mould was being filled, it was tilted to upright position where the final solidification was completed similar to gravity casting. Slightly larger cross-section was selected for tilt casting due to the elimination of temperature loss and solidification during controlled slow filling which was established by Sahin [41].

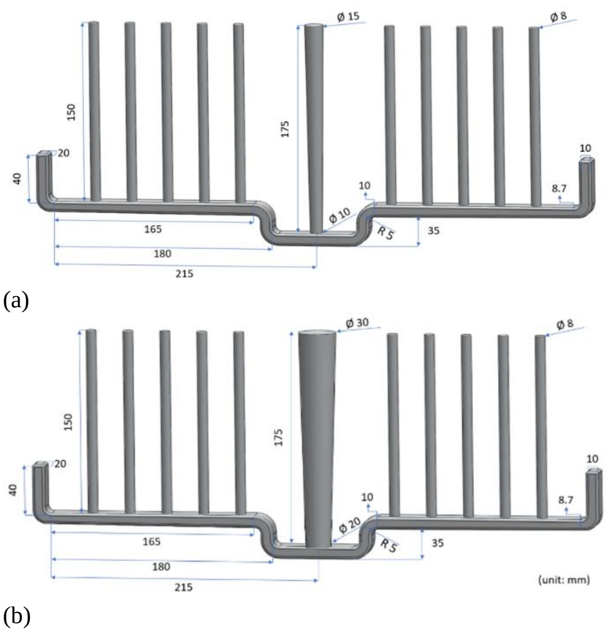


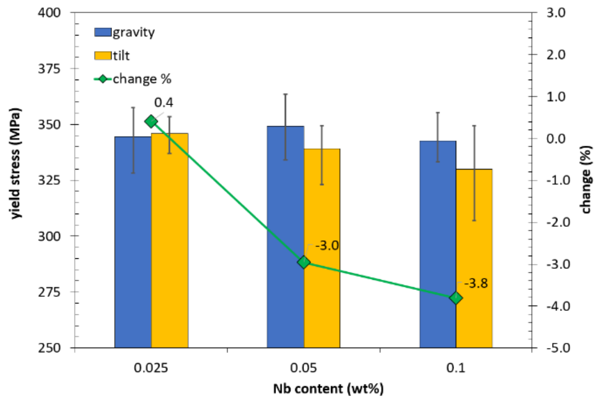
Fig. 1. Dimension of tensile mould used in the experiments (a) gravity, (b) tilt casting

Samples were subjected to T7 heat treatment: 22 hours solutionizing at 540ºC, quenching in water at room temperature, 24 hours natural aging at room temperature, followed by 13 hours at

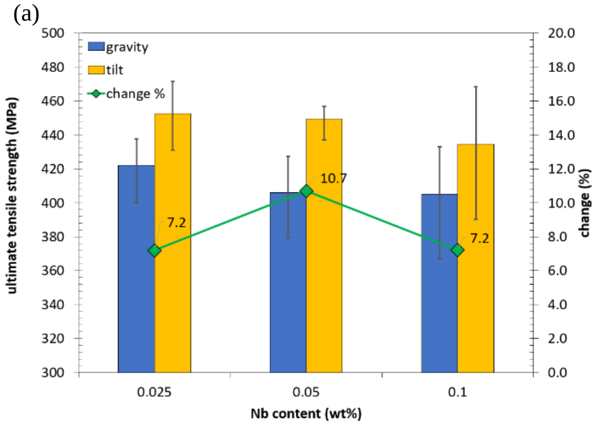
160ºC for artificial aging. Samples were machined to ASTM E8 standards and subjected to tensile testing on Zwick 250 kN.

3. Results

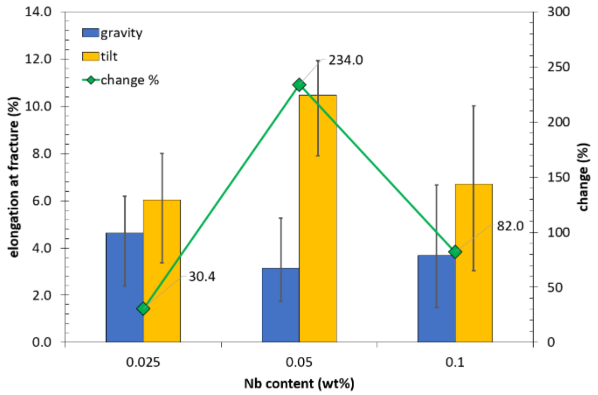
The tensile test results comparing the gravity and tilt casting of Nb grain refined A206 alloy is given in Figure 2. The characteristic property of A206 which is the yield stress does not vary with the casting method. An average around 340 MPa (±10) was recorded for both conditions (Figure 2a). However, ultimate tensile stress was increased by 7% from an average of 410 MPa to 440 MPa for gravity and tilt casting respectively (Figure 2b). More significant increase was observed in the elongation at fracture values where this value was increased from around 3% towards 7.7% (Figure 2c). Similarly, toughness was also increased by 2 folds (Figure 2d) when the mould was filled by tilt casting. Although the cooling rate and solidification was the same in both cases (i.e. same grain size), the increase in toughness was attributed to the elimination of the folded oxide defects during filling.



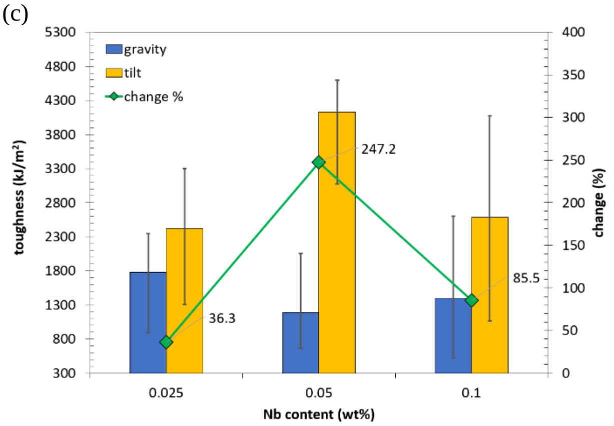
(a)



(b)



(c)



(d)

Fig. 2. Tensile property results comparing tilt casting versus gravity (a) yield stress, (b) ultimate tensile stress, (c) elongation at fracture, (d) toughness.

In Figure 3, a crumpled folded oxide caused by the turbulent filling can be seen on the fracture surface.

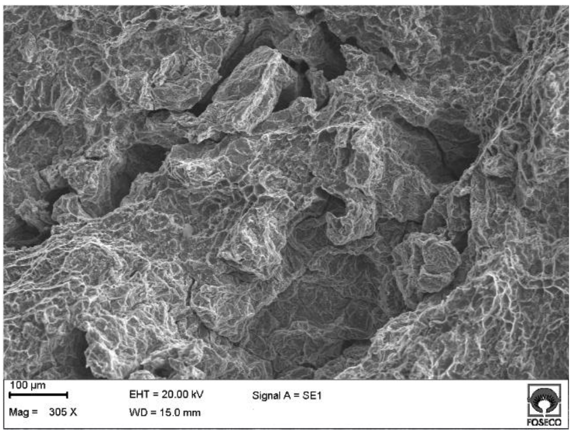


Fig. 3. SEM images of fracture surface with turbulent filling

4. Conclusions

More quiescently the mould cavity was filled, higher the toughness of A206 alloy was achieved. Aluminum surface oxidizes rapidly, and during the filing process, if turbulence occurs, these folded oxides are introduced into the cast part which act as inclusion and initiation for crack formation, thereby the toughness of the cast parts decreases. Thus, the elimination of entrained oxides defects into the cast part (mainly by keeping the melt velocity under 0.5 m/s critical velocity which was achieved by tilt casting in this work) increased the toughness Nb grain refined A206 alloy significantly.

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