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Abstract— In thepresent investigation, the effect of Al–5Ti–1B grain refiner on the microstructure and mechanical properties ofheat treated Al 336 aluminium alloy have been studied. Microstructural analysisshowed the transition of needle like silicon to globular silicon after theaddition of the grain refiner.

The results indicated that the addition ofAl–5Ti–1B grain refiner into the alloy caused a significant improvement inultimate tensile strength (UTS) values from 330. 16MPa to 363. 69MPa.

TheRockwell hardness values of the cast specimen also showed an increase. The mainmechanisms behind this improvement were found to be due to the grain refinementduring solidification of the melt. Keywords—microstructure, Al-5Ti-1B, grain refinement, tensile strength, mechanical properties

I. INTRODUCTIONAl–Si alloys are excellent substitutes for cast ironused in automobile industries. Addition of silicon to aluminium gives highstrength to weight ratio, low thermal expansion coefficient and high wearresistance 1, 2.

These alloys also show improved strength and wear propertiesas the silicon content is increased beyond eutectic composition. The microstructure of hypo-eutectic aluminium alloysmainly consists of primary ?-Al dendrites and eutectic silicon in the solidsolution. The microstructure of hyper-eutectic Al-Si alloy consists of primarysilicon in the eutectic matrix. The refinement of grains of the hypo-eutecticalloys results in the formation of fine equiaxed ?-Al dendrites and theimprovement of the mechanical properties. Experiments on the grain refinement of Al-Si alloys wereconducted using many refiners like Al-Ti master alloy, strontium, Al-Ti-Bmaster alloy, etc.

The Al–Ti–B ternary master alloys have been commonly used asgrain refiners for most aluminium alloys owing to their low costs and excellentresults 3. The mechanism of grain refinement of Al-Si alloys by Al-Ti-Bmaster alloy is quite complex and after several decades of research, no clearconsensus has been reached yet on the mechanism. Easton and Stjohn 4described the mechanism of grain refinement as nucleant and solute paradigms. The nucleant paradigm refers to the heterogeneous nucleation of primary ?-Algrains on insoluble substrates, which acts as nucleation sites. The soluteparadigm includes the role of solute elements on grain refinement process. Mohanty et al. 5 studied the mechanism of grain refinement in aluminiumalloys by directly adding TiB2 crystals into the aluminium melt. Theyobserved that the TiB2 particles were found in the grainboundaries and the Ti atoms segregate at TiB2/melt interfaceresulting in the formation of a thin layer of TiAl3.

Thisundergoes a peritectic reaction to form primary ?-Al. Johnsson et al. introduced the solute theory to explain the grain refinement of aluminiumalloys due to the addition of Al–Ti–B master alloys 6. They suggested thatboth nucleant and solutes particles influence the grain refinement. The solutetitanium atoms segregates and restricts the growth of nucleant particles thusmaking available larger number of nucleating sites for nucleation of primary ? grains. Though a number of theories have been proposed toexplain the grain refinement in aluminium alloys, none of these could clearlyexplain the exact mechanism. Some recent trends in grain refinement of Al-Si alloysinclude reduction of grain size under the influence of a travelling magneticfield (TMF) 15.

Theformation of a fine equiaxed structure was obtained by both the addition ofgrain refining AlTi5B1-particles and electromagnetic stirring. Friction stirprocessing (FSP) provides micro-structural modification and control in the near-surfacelayer of metal components 16. FSP of cast Al and Mg alloys resulted in thebreak-up of coarse dendrites and secondary phases, refinement of matrix grains, dissolution of precipitates and elimination of porosity, thereby improving themechanical properties of the castings significantly. Improvements in thetraditional Al-Ti-B grain refiner in the recent times have also improved thecapability of the grain refinement process. New grain refiners, such as Al–3Band Al–3Ti–3B master alloys with excess-B have been developed with welldocumented advantages for Al–Si alloys 17. TABLE I. CHEMICAL COMPOSITION OF Al 336

Al 336 Constituents Si Fe Cu Mn Mg

Zn Ni Cr Pb Ti Sn Al Constituents

percentage 11 – 13 0.

6 1. 5 0. 1 1 0. 3 1.

5 0. 02 0. 018 0.

03 0. 011 Bal TABLE II. CHEMICAL COMPOSITION OF

Al 6061 Al 6061 Constituents

Si Fe Cu Mn Mg Zn Ni Cr Others Al

Constituents percentage 0.

6 0. 7 0. 3 0. 15 1 0. 3 0 0. 04 – 0. 3 0.

05 – 0. 15 Bal The present paper aims to study the effect of Al–5Ti–Bgrain refiner on microstructure and mechanical properties of Al 336 aluminiumalloy on the account of grain refinement. Al 336 is eutectic Al-Si alloy.

II. EXPERIMENTAL PROCEDUREThe chemical composition of Al 336 alloy is shown inTable I. Al 336 alloy was prepared using Al 6061, Al-50%Cu, Al-50%Si andAl-10%Ni master alloys as the starting material. The chemical composition of Al6061 alloy is shown in Table II. The required weights of each alloy arecalculated before melting. Next, the masteralloys were melted in a diesel fired tilting furnace at 750–800 ? C using a graphite crucible. After stirring, the molten metal was poured intothe pre-heated cast iron moulds to prepare cast rods of Al 336 alloy.

Two moulds were used to pour the molten metal. Thegeometry of the moulds were, square prism of side 35mm and height 300mm and acylindrical mould of diameter 40mm and height 350mm. Fig 1. As cast specimens, from left to right, unrefined Al336, Al 336 with 0. 5 wt.

% Al-5Ti-B, Al 336 with 1 wt.% Al-5Ti-B The procedurewas repeated to prepare castings of two different grain refined alloys with 0. 5and 1 wt% Al–5Ti–1B grain refiner respectively. The as cast specimens are shownin Fig 1. The castspecimens were then heat treated using a 30kW electrical furnace. The heattreatment process carried out was T6 process. The T6 heat treatment includessolution treatment and aging treatment.

The solution treatment was firstlycarried out at 470 °C for 6 h, and then quenched into water. The agingtreatment was then performed at 225 °C for 8 h. Microstructural characterizationswere carried out of the heat treated samples using LEICA 5000 M opticalmicroscope. The metallographic samples for microstructural characterizationwere cut from the centre of the cast ingots. These samples were etched withKeller's reagent after polishing. Fig 2. Rockwell hardness test specimens of diameter 40mm Hardness was measured using theRockwell hardness tester on " B" scale with 1/8″ steel ball indenter with minorload of 10 kg, and major load of 100 kg on the cast specimens.

The sample wasplaced on anvils and major load of 100 kg was applied up to 6 seconds. Theaverage hardness values of inner and outer regions for each sample arereported. The hardness test specimens were cut from the cylindrical castingots, Fig 2. Cylindrical tensile specimens ofdimensions of 4 mm diameter 50 mm gauge length were cut from the cast ingots ofboth the as cast and grain refined alloys according to ASTM E08 standards, Fig3. Tensile tests were carried out using universal testing machine of capacity30kN at room temperature with a 10 mm/min stretching rate. Fig 3. Tensile test specimens, cut according to ASTM E8standards

III. RESULTSA.

MicrostructuralanalysisThe microstructures of heat treated Al 336 aluminiumalloy before and after grain refinement is shown in Fig. 6. It is clear fromthe figure that addition of Al–5Ti–1B master alloy resulted in grain refinementof Al 336 alloys. From Fig. 6a and Fig. 6b it was found that the microstructureof unrefined Al 336 alloy consists of long needle like silicon. The addition ofAl–5Ti–1B to Al 336 alloy resulted in the transformation of needle like siliconto globular silicon Fig. 6c.

The eutectic matrix in grain refined alloy wasalso uniformly distributed and finely spaced. This ensures the uniformdistribution of insoluble substrates in the matrix, which acts as sites forprimary ?-Al nucleation. The averagesize of Si needles in unrefined alloy is 61µm while in 1% Al-5Ti-B refinedsamples, it is 31µm. Grain refinement lead to the breaking down of the long Sineedles. This results in the formation of globular Si, Fig 6f. The averagediameter of the globular Si is 15µm. The microstructure of non-grain refined Al 336 Fig. 6ashowed the presence of primary silicon plates.

This may be due to change in thecasting conditions which may have resulted in the shifting of the eutecticpoint. B.   MechanicalPropertiesTable IV shows the hardness values of unrefined andAl–5Ti–1B refined alloys. The hardness values of the outer regions of thecastings were better than the inner regions. Fig.

4 shows the comparison ofhardness vales of all the specimens. The stress strain curves of unrefined and refined Al 336alloys are shown in Fig 7. The tensile test resulted in brittle fracture of thecast specimens with very little elongation. The UTS values of the alloyincreased from 330. 16MPa to 363. 69MPa for refined Al 336.

The tensile testresults are provided in Table III.   Fig

4.   Rockwell hardness of A) unrefined Al 336 (B) Al 336with 0. 5 wt.%

Al-5Ti-B (C) Al 336 with 1 wt.% Al-5Ti-B Fig 5. UTS of A) unrefined Al 336 (B) Al 336 with 0. 5 wt.

%Al-5Ti-B (C) Al 336 with 1 wt.% Al-5Ti-B

IV. DISCUSSIONA.

Effect ofGrain Refiner on MicrostructureThemicrographs, Fig. 6, clearly show that transition of needle like silicon toglobular silicon. Several researchers have explained grain refinement inaluminium alloys due to the addition of Al–5Ti–1B master alloy in terms ofdifferent theories such as carbide/boride theory 7, phase diagram/peritectictheory 8, 9, peritectic hulk theory 10, 11, duplex nucleation theory 12, 13, and solute theory 6, 14. Cibula et al.

9, 14 observed that the use ofAl–5Ti–1B as grain refiner, introduces both titanium and boron in to the meltin the form of AlB_2, TiB_2 and Al_3Ti. They suggested that TiB_2 particles act as insoluble substratesfor primary ?-phase nucleation. In comparison to TiB_2, Al_3Ti was found to be a better nucleant mainly due to its goodorientation relation-ship with aluminium 10. Johnsson and Bakrued proposedthe solute theory, which suggested that both addition of solute atoms andnucleant particles are vital for grain refinement of aluminium alloys.

Fig 6. Microstructures of (a, b) unrefined Al 336 (c, d) Al336 with 0. 5 wt.% Al-5Ti-B (e, f) Al 336 with 1 wt.% Al-5Ti-B TABLE III. Tensile Test Results Tensile Test Sample 0% grain refiner 0. 5% grain refiner 1% grain refiner Tensile Strength(MPa) 330. 16 353.

11 363. 69 Maximum 1. 008 0. 994 0. 958 Elongation(%)

Load at peak(kN) 4. 15 4. 44 4.

62 TABLE IV. Hardness Values Hardness test Sample

0% grain refiner 0. 5% grain refiner 1% grain refiner Middle (HRB) 57

57 59 Outer (HRB) 57 61 63 (b) (a) (c)

Fig 7. Stress-Strain diagram of (a) unrefined Al 336 (b) Al336 with 0. 5 wt.% Al-5Ti-B (c) Al 336 with 1 wt.

% Al-5Ti-BB. Effect of Grain Refiner on MechanicalPropertiesThe hardness was found to increase withincrease in Al–5Ti–1B content, which is mainly attributed to the refinement ofgrains. From the microstructural observation, it is evident that the additionof Al–5Ti–1B to Al 336 alloy resulted in improvement in morphology of Sineedles to globular Si. Long Si needles are a source of stress concentrations. These changes lead to an improvement intensile properties of refined Al 336 alloy. The increase in mechanical properties was foundto be decreasing with the increase in concentration of the grain refinerAl-5Ti-1B.

This may be due to the formation and settling of inter-metalliccompounds formed during the melting process.

V. CONCLUSION In the present work, the effect ofAl–5Ti–1B grain refiner on microstructure and mechanical properties of Al 336alloy was studied. The following conclusions can be drawn based on theexperimental results. The morphology of Al 336 changes on the addition of Al-5Ti-B grain refiner. The needle like silicon in the eutectic matrix gets transformed to globular silicon.

The eutectic matrix is also uniformly distributed for refined Al 336. The mechanical properties of Al 336 alloy were improved by the addition of Al–5Ti–1B master alloy. The ultimate tensile strength values were increased from 330. 16MPa to 363. 69MPa for refined Al 336. The hardness was also found to increase on the addition of the grain refiner for refined Al 336.

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