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ROLE OF Ti & B IN MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A 360 ALLOY

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ABSTRACT

In this investigation, the Role of Ti & B in microstructural and mechanical properties study of A 360 alloy, have been discussed. The microstructural aspects of cast A 360 alloy are strongly dependent on the grain refinement (Ti and B). The mechanical properties such as Tensile Strength, UTS, %E, BHN and toughness have been investigated. This journal deals with the grain refinement of A 360 and thereby improving the overall mechanical properties of the alloy. The quality of castings and their properties can be achieved by refining of α-Al dendrites in A 360 alloy by means of the addition of elements such as Ti and B which reduces the size of α-Al dendrites, which otherwise solidifies with coarse columnar α-Al dendritic structure.

KEYWORDS: A 360 Alloy, Grain Refinement, Mechanical Properties, α-Al Dendrites

INTRODUCTION

Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Nowadays aluminium alloys are largely used in automobile applications like cylinder heads of airplanes & motorcycle, aircraft motor and gear housing, turbochargers etc. Aluminium alloys also have very common applications like frying pan, instrument cases etc. As we know aluminium cast alloys have 100 to 800 series and of which 300 series is mainly used and of 300 series 356 have prominent applications. The other aluminium alloys is not used because of its poor overall mechanical strength which is due to α-Al dendrites which forms a coarse columnar structure and silicon forms brittle needle-like particles that reduce impact strength. So by adding refiners like Ti and B, grains can be refined and thus we can get a non dendritic structure which further increase the mechanical properties.

The microstructure and alloy constituents are necessitated to achieve optimum mechanical properties. Si content is A 360 alloys employs this alloys to be cast easily because of the fluidity. However, eutectic Si particles present along solidification cells of the A 360 aluminum alloy deteriorate strength, ductility, and fracture toughness and thus researches to develop processes for enhanced distribution of eutectic Si particles have been actively pursued. It is well known that on solidification of hypoeutectic Al-Si alloys the primary α-Al solidifies with coarse columnar or twinned columnar. Actually, in most cases high-level mechanical properties are needed for industrial applications, so the performance of the alloy must be subject to many micromechanical investigations. Since the strength and hardness of alloys mainly depend on their microstructure, by refining the structure mechanical properties can be improved.

The main variables affecting the microstructure include composition, solidification conditions, Stirring time and heat treatment. Here in our experiment we are concentrating only on composition and stirring time. Mechanical properties of Al-Si alloys are related to the morphology of aluminium and silicon particles (size, shape and distribution), grain size, shape and dendrite parameters. Modification by adding refiners changes the morphology of aluminium and silicon particles. Addition of Ti causes reduces the size of alpha Al dendrites which otherwise solidifies as coarse columnar structure. Fine grain size increases strength and ductility. Compared to boron, $TiAl_3$ crystals are poor nuclei. $TiAl_3$ crystals also have a relatively high solubility in aluminium. For both reasons a large amount of titanium must be added to produce consistently small grain sizes. As in the case of B, it combines with other metal to form borides, AlB_2 and TiB_2 and thereby increasing hardness. It also has a stable nucleation to activate grain refining. Titanium diboride has almost no solubility in liquid aluminium so good refinement at small addition levels. But on the other hand High boron concentration, borides contribute to particle agglomeration, and increased risk of casting inclusions.

Thus, keeping in view, an attempt has been made to study the effect of additions of Ti and B in the form of master alloys on the microstructure and mechanical properties of A 360 alloy.

Best Practices for Grain Refinement

Before defining the best grain refinement practices, it is necessary to clearly distinguish between the two forms of titanium:

- **Soluble Titanium**

This is the TiAl3 compound, which is present as 10-20 micron sized particles in Al-Ti master alloys which do not contain boron. It is also present in Al-Ti-B alloys which have an excess of Ti required to produce TiB2. (The stochiometric ratio is 2.22 wt % Ti for each 1 wt % B.) The TiAl3 compound dissolves quickly in alloys that contain less than about 0.15% Ti. As noted above, this particle is a poor refiner in Al-Si casting alloys.

- **Insoluble Titanium**

This is the titanium present as TiB2. TiB2 has such a low solubility in aluminum, that for all practical purposes it can be considered to be insoluble. (TiC is another form of insoluble titanium. The carbide is also a good grain refiner, but as it offers no advantage in casting alloys, Al-Ti-C refiners will not be considered further.

CASTING OF A 360 ALLOY

For casting of A 360 Alloy, Aluminium 360 alloy ingots are used. For modification Master alloy of Ti and B in powder is used as mentioned below.

Material Selection

- Al alloy ingot
- Master alloy – Powder
- Coverall flux

- De-gasser

Details of Materials Used

Aluminium Ingot

- Aluminium waffle ingot - 10 kg

Master Alloy (10% wt)

- Powder form
- Size 6 µm
- Titanium Boron Aluminium 3% Ti – 1% B
- 1 Kg

Coverall Flux (1% Wt)

- 47.5% NaCl, 47.5% KCL and 5% NaF
- Melting Temperature – 607^{0}C
- 100Gm

Degasser (0.5% wt)

- Hexachloroethane Tablet / perchloroethane (PCA)
- Melting temperature – 1840c
- 50Gm

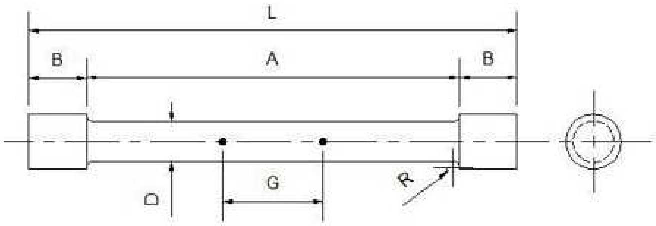
Procedure of Casting

- Prior to the charge of ingots into the crucible they have to be cleaned by abrasive and chemical solvent (acetone). This is done to make the casting free from casting defects caused by impurities in the metal and to make it free from moisture to prevent corrosion.
- 10Kg of A360 Waffle ingot is weighed using a weight balance. The induction furnace is heated to 700oc to become red hot and the A 360 alloy is charged into the crucible.
- Coverall flux of 100gm is also added when the temperature is in the range of 5800C into the crucible while charging the alloy. The purpose of adding the flux is to prevent the melt surface from oxidation and contamination.
- Add hexa - chloro ethane at 7000C max to degas the melt alloy i.e, to drive away the dissolved hydrogen, which will otherwise be present in the solidified ingot as porosities
- To remove further the dissolved hydrogen and nitrogen gas is bubbled through the molten metal. Here nitrogen gas is bubbled for about 45 minutes. This will ensure that all the hydrogen present in the molten metal is removed.

- Add the master alloy in powder form – 1kg to the crucible and complete melting is ensured.
- After Ti & B addition nitrogen gas is again bubbled for about 15 minutes as mentioned above.
- Mechanical stirring is done at a temperature of 5800C for 20 min at 425 rpm in order to mix the elements well and mainly to acquire the required mechanical property
- Molten aluminium is poured into a testing cup to analyze the composition.
- Testing is done by using Squish Analyser. If the required composition is attained proceed to pour it into the mould, if not add master alloy and check again. Care should be taken to degas the molten metal again.
- The molten metal is poured into the preheated moulds. Then the moulds are allowed to solidify. After solidification, the casting is removed from the mould

Figure 1: Cast A360 Alloy

EXPERIMENTAL DETAILS



G – Gauge Length	2.000 ± 0.005
D – Diameter	0.500 ± 0.010
R – Radius of Fillet, Min	1/16
A – Length of Reduced Section	4
L – Overall Length	5½
B – Length of End Section	¾

All Dimensions in Inch

Figure 2

Tensile Testing as per ASTM B557 – 06

Tensile testing was done as per ASTM B557 06. The details of samples are given below. The cut portion from the cast is turned to obtain the tensile test specimen. Photographs are shown below

The tensile properties (ultimate tensile strength and % elongation) were measured by using a Universal testing machine Instron model 1195, at room temperature. The test was carried out by gripping the ends of the specimen on the Instron machine and applying increasing pull on the specimen till it fractures. Tensile tests are carried out for determining the mechanical properties like tensile yield strength, Ultimate Tensile Strength (UTS) and % Elongation to check whether the material is tensile or brittle.

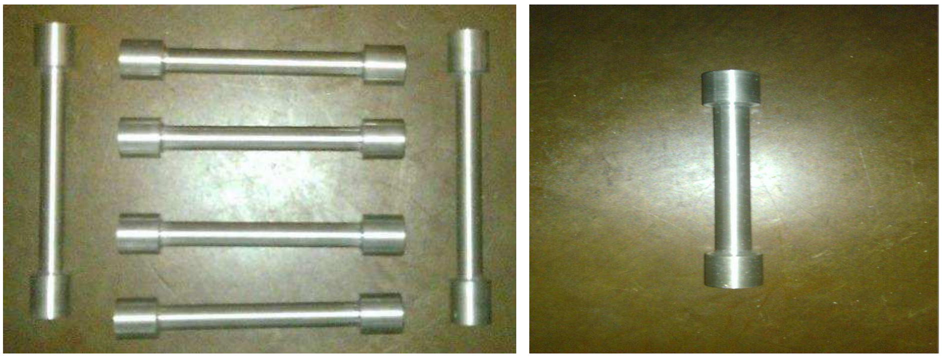


Figure 3: Specimens for Tensile Test

Impact Testing as per ASTM E23

Various standard impact tests can be employed to test the toughness of material but here we are using Type A as given below, i.e. V notch test is done. The notched specimens are broken by a swinging pendulum. 6 specimens are used for testing and mean is taken as the toughness value or impact strength in J.

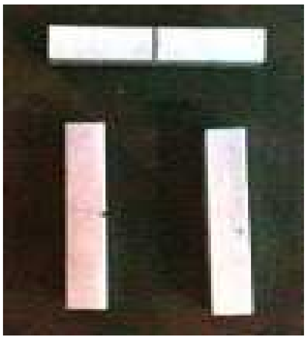


Figure 4: Test Specimen for Impact Test

CVN Impact Testing reproduces very strenuous service conditions (high strain rates, triaxial stress state due to the presence of sharp notches, and low temperatures

Hardness Testing as per ASTM E18

ASTM E 18 relates with Rockwell hardness testing. In our test we are using B scale i.e. we will get HRB. The load used is 100kgf. ASTM E140 - 07 – Standard Hardness Conversion Table also can be used to convert the HRB scale to the required other scales, say VHN, BHN, HRC etc. 3 Specimens are made by size 40mm X 40 mm. Five reading from each specimen is taken and then the average is calculated to get the hardness of the modified alloy.

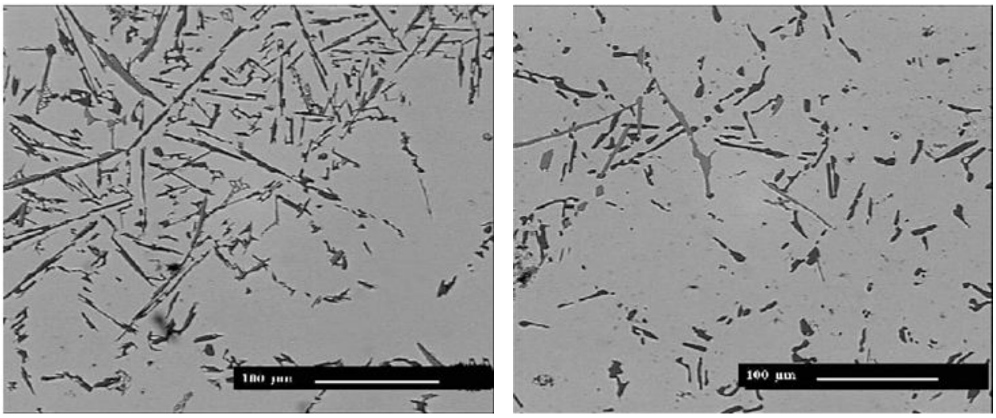
Metallography

Two small cylindrical specimens, of dimension 15x15, were cut from the bottom of the castings. The as-cast as well as modified samples were polished for microstructure study. Samples are polished initially by silicon carbide papers of different grades. Hand polishing was followed by machine polishing. Diamond paste with particle size 6µm, 3µm, 0.25µm were progressively used. The polished samples were chemically etched using 0.5% HF solution to reveal the microstructure. After etching and thorough cleaning in running water the samples were dries using hair drier and observed under optical microscope.

RESULTS AND DISCUSSIONS

Microstructure Analysis

- Microstructure of unmodified A 360 alloy and Modified A 360 alloy is taken to understand the morphology at 100µm.
- The Needle like structures in the microstructure of unmodified A360 is coarse α-Al Dendrites. The grey colour surrounding the needle structure is the Al matrix.
- The dark black dot shows the porosity in the casting.
- In the Microstructure of modified A 360 alloy we can find out that the needle structure is reduced i e the microstructure is refined or the grain size has been reduced.
- Addition of Ti and B changes the microstructure – it reduces the size of alpha – Al Dendrites, which otherwise solidifies with Coarse columnar structure.
- Grain size is refined by increasing the solidification rate but is also dependent on the presence of grain-refining elements (principally titanium boron) in the alloy.
- Adding a small quantities of modifiers, here Ti & B causes modification of the microstructure. This addition effectively moves the eutectic point to a higher silicon concentration and lower temperature. This modifies the growth of the eutectic silicon to produce an irregular fibrous form rather than the usual flakes. The eutectic point has moved far enough to make the alloy, at this composition, hypo-eutectic instead of hyper-eutectic. So now primary alpha forms, rather than primary Si. This can be seen on the microstructure.
- Al-Si alloy solidifies, the primary aluminium forms and grows in dendrites or silicon phase forms and grows in angular primary particles. When the eutectic point is reached, the eutectic Al-Si phases nucleate and grow until the end of solidification.



(a) (b)

Figure 5: (a) A 360 Alloy – Unmodified (b) Modified A 360 Alloy

Tensile Test Results

Table 1

Sl No	Tensile Yield Strength in MPa	Ultimate Tensile Strength in MPa	% Elongation(% in 2'' G.L)
1	162	323	3.8
2	169	319	3.5
3	172	320	3.8
4	166	316	3.4
5	165	323	3.4
6	170	320	3.5
Standard Deviation	**3.35**	**2.41**	**0.17**
Mean	**167**	**320**	**3.6**

Tensile test of the modified A 360 alloy was carried out as per ASTM standard. The Tensile yield strength of unmodified A 360 alloy is 165 MPa. As from the table we can see that six numbers of specimen was tensile tested and it was found that the tensile yield strength of modified A 360 alloy has been increased to 167 MPa.

From the table we can find out that ultimate tensile strength of modified alloy is increased from 317 Mpa to 320 Mpa. % Elongation, which was 3.5%, has been increased to 3.6 %. Tensile strength has increased because of the grain refinement of A 360 alloy by adding the Ti & B.

It is also evident that there is not much increase in the strength which is due to Increased B addition, high boron concentration leads to the formation of borides which makes the alloy hard and brittle thereby reducing the tensile strength also high B concentration contribute to particle agglomeration. The modified A 360 is not heat treated. If heat treatment is done, Precipitation hardening occurs also the nucleus formed in the casting gets more time to grow and thus it will be refined and thereby increasing the tensile properties.

Hardness Test Results

Table 2

Sl No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
HRB	79	80	78	78	79	79	79	80	82	79	80	78	79	79	79

Standard Deviation – 0.98
Mean – 79

AlB_2* (Aluminium diboride) & *αAlB_{12}* (Aluminium dodecaboride)** which is formed by the addition of Boron is very brittle structures which increases the hardness of the modified A 360 alloy. ***TiB_2 which is formed by the addition of Ti and B also increases the hardness. Though titanium diborides are formed very little they are very brittle structure which can adversely affect the mechanical properties.

The formation of Intermetallics also contributes to the increase of hardness. Needle-like α Al_5FeSi intermetallics these are very brittle phases which cut the matrix.

Note: The Specimen for hardness is taken from the bottom side of the casting that means the solidification time at the bottom of casting is longer and therefore the grains will be perfectly refined and the carbides will be fully formed and placed in proper manner.

Charpy Impact Test Results

Table 3

Sl No	Impact Strength in J
1	5.7
2	5.4
3	5.7
4	5.4
5	5.3
6	5.5
Standard Deviation	**0.15**
Mean	**5.5**

Needle-like α Al_5FeSi intermetallics which is a brittle phase cuts the matrix and produces stress concentration and thus greatly degrades the mechanical properties of Al-Si alloy. By combining all the result we can see that, toughness is mainly affected mechanical property.

Brittle Eutectic Silicon phase also degrades the impact property of the alloy. Microporosity usually resulting from the dissolved H_2 and N_2 gas is also a reason to reduce the impact strength of the alloy. When molten Al-Si alloy solidifies, the hydrogen atoms precipitate from the melt and form molecular hydrogen which forms porosity act as a stress concentration point to initiate the crack formation.

Failure occurs in Al-Si alloy mainly by nucleation and propagation of microcracks around silicon phase or in aluminum matrix. Silicon is brittle and can easily crack. Decohesion of silicon from the aluminum matrix also takes place. Microcracks usually initiate from these sites and then propagate.

The dislocation slip band in the matrix is a kind of microcrack initiator. The matrix has areas where there is no reinforcement such as silicon particles or intermetallic precipitates. These local non-reinforced areas are relatively soft and dislocation slip can be easily produced under external stress. When the slips accumulate at part surface or grain boundaries, a localized strain is produced and an even microcrack is initiated. Also it can be inferred that as the hardness of the alloy increases the toughness decreases.

CONCLUSIONS

A 360 alloy was modified by adding Ti and B and results were obtained. From the microstructure it is evident that modifiers added helps in refining the grain structure which in turn improves the mechanical properties. By adding modifiers the needle like structure ie α Al was reduced and also the silicon which forms the brittle phase is also reduced.

Tensile properties were improved. The tensile yield strength was increased from 165 MPa to 167 Mpa. Also from the tests it was found that UTS and % Elongation is also increased. UTS is increased from 317MPa to 320 Mpa and % elongation (% in 2’’ G.L) 3.5% to 3.6%.

Impact strength or the notch toughness of the modified alloy is found to be decreased from 5.7J to 5.5 J which is due to the formation of intermetallics and microporosity formation by the include gases like H_2 and N_2.

Hardness of the modified alloy was tested by taking 5 reading from each samples and 15 reading were taken.

The Hardness of modified alloy was found to be increased from 75 HB to 79HB which is due to the formation of intermettalics and borides.

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