Influence of the Hardness on Treated A413 Alloy

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Abstract—Treatment is an operation or combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at specified rate. The aim is to obtain a desired microstructure to achieve certain predetermined properties (physical, mechanical, magnetic or electrical). To ensure that any metal or alloy (Al-Si) component is suitable and adequate for the designed purpose, it may need to be exposed to a selected range of conditioning and finishing treatments. The treatments are conducted in such a way so as to ensure that the required combinations of these parameters are carefully controlled to achieve the desired finished component. The investigation done is the fact that aluminium-based alloys, especially Al-Si alloys, which account for their popularity and its wide spread applications on the hardness. A study was therefore planned for the hardness of Al-Si alloys (A413) under treated conditions.

IndexTerms—A413, Heat Treatment, Hardness.

I. INTRODUCTION

The principal purpose of the hardness test is to determine the suitability of a material for a given application, or the particular treatment to which the material has been subjected [1-2]. The ease with which the hardness test can be made has made it the most common method of inspection for metals and alloys.

The commercial application of aluminum casting alloys perhaps Al-Si alloyis the most common particularly due to some very attractive characteristics such as high strength to weight ratio, excellent castability and pressure tightness, low co-efficient of thermal expansion, good thermal conductivity, good mechanical properties and corrosion resistance. Also find wide applications in marine castings, motor car and lorry fittings (pistons), engine parts (casing), cylinder blocks and heads, cylinder liners, axles and wheels, rocker arms, automotive transmission casings, water cooled manifolds and jackets, piston for internal combustion engines, pump parts, high speed rotating parts and impellers etc.

The binary Al-Si alloys belong to the simple eutectic system, the eutectic temperature being 577 $^{\circ}$ C. But the composition of the eutectic point has been reported ranging from 11.7% - 14.5% Si with the most probable value at 11.7% Si. The eutectic composition in binary Al-Si system is known to shift depending on the alloying elements and cooling conditions or casting processes involved. Al-Si alloys are classified into three groups depending on their composition. These are hypoeutectic (<10% Si), eutectic (10-13% Si) and hypereutectic (>13% Si) Al-Si alloys. Silicon is probably one of the least expensive alloying additions commonly made to aluminum.

The silicon content in standardized commercial cast aluminum silicon alloys is in the range of 5 to 23wt%. Silicon has a low density (2.340 g/cc), which may be an added advantage in reducing overall weight of the cast components. Further, silicon has a diamond crystal structure and is consequently very hard and brittle and has a very low solubility in aluminum and it is therefore precipitates as virtually pure silicon and hence improves mechanical properties of these alloys. Silicon improves castability, increases strength to weight ratio, enhances corrosion resistance, decreases the coefficient of thermal expansion and imparts wear resistance and machinability. The most widely employed aluminum silicon alloys are often hypoeutectic and eutectic. Hypoeutectic Al-Si alloys find wide application in the marine, automobile and aircrafts where it is used for cylinder blocks and heads and other engine body castings. Alloys with 3-5% silicon are used in rotors, vessels, valve bodies, large fan blade fittings etc. These are mostly used in as cast condition. Alloys with silicon content <3% are used in heat-treated condition for marine fittings. Alloys with 7% silicon find wide application in the marine, electrical, automobile and aircraft industries where they are used for cylindrical blocks and heads and other engine body castings. Eutectic Al-Si alloys [10-13% silicon] find wide applications in marine, chemical, food and domestic, electrical automotive, aeronautical sectors and engine parts. Hypereutectic alloys [>13% silicon] are used primarily in the production of diesel engine pistons, cylinder liners, rocker arms, cylinder blocks, cylinder heads and brake drums. These alloys possess outstanding wear resistance, low thermal expansion coefficient, very good casting characteristics, excellent fluidity, excellent machinability in terms of surface finish and chip characteristics. But, presence of extremely hard Si phase reduces tool life during machining.

Basically, the microstructures of Al-Si alloys consist of the primary phase α -Al in hypoeutectic and primary Si in hypereutectic alloy and Al-Si eutectic constituent. The morphology, volume fraction, size, and distribution of the primary phase and the eutectic constituent in the microstructures depend on the composition and solidification/casting process involved. It is essential that these

alloys solidify with equiaxed α -Al in hypoeutectic, fine primary Si particles in hypereutectic and fine eutectic Si. While the former can be achieved by suitable grain refinement treatment/solidification processing, the latter is achieved by modification. A fine grain size ensures improved mechanical properties, improved feeding during solidification, reduced and more evenly distributed shrinkage porosity, good tribological properties, uniform distribution of second phase particles on a fine scale and good surface finish resulting in improved machinability. The wear resistance of these alloys may depend on the hardness of the matrix and the dispersed second phase Si particles/plates in the Al-Si alloys. The distribution state of the Si particles in the Al-Si alloys can be changed by modification [3]. Therefore, Al-Si alloys are suitable for studying the effect of second phase particle on the mechanical properties of the alloys.

It is well known that metals and alloys solidify with coarse columnar grain structure under normal casting conditions unless the mode of solidification is carefully controlled. It is possible to develop fine equiaxed grain in the cast structure either by increasing the number of nucleation sites or by grain multiplication [3]. There are other methods such as melt agitation and vibration during solidification or use of mold coating. Among all these techniques, grain refinement by inoculation has become the most popular due to its simplicity. The interest in grain refinement technique stems from the fact that the mechanical properties of any metal or alloy component are greatly enhanced by grain size. Grain size is one of the important parameter in determining the mechanical properties of Al-Si alloys and according to Hall-Petch equation, high strength can be attained in fine-grained Al-Si alloys.

Attempts have been made in the past to achieve fine equiaxed grain structure by small additions of several elements like Ti, B, Zr, Nb, V, W, Ta, Ce etc. (commonly referred to as hardeners) to molten metal prior to casting. Refining of α -Al grains in Al-Si alloys by means of the addition of elements such as titanium or boron is a common industrial practice. Ti and B containing master alloys find wide popularity, as these were more effective and less expensive than others. Several types of grain refiners in the form of master alloys (Al-B, Al-Ti and Al-Ti-B) are used for grain refinement. The production of these master alloys involves addition of inorganic halide salts like potassium titanium fluoride (K_2TiF_6) and or potassium borofluoride (KBF₄) to molten Al. These complex salts react with liquid Al efficiently producing a melt with dispersed particles of TiAl₃ and (Al, Ti) B₂ in final alloy. These particles act as heterogeneous nucleating sites during solidification of Al-Si alloys. The weight ratio required to form the nucleating TiB₂ particle is Ti/B=2.2/1, although all commercially manufactured grain refiners present higher ratio of Ti/B, such as 3Ti-1B, 5Ti-1B, 5Ti-0.2B. The ternary Al-5Ti-1B master alloy is an efficient grain refining power of this master alloy is lower than that of Al-3B and Al-3Ti-3B alloys. It was also reported that Al-1Ti-3B master alloy show better response towards grain refinement of Al-7 and 12Si alloys when compared to Al-5Ti-1B master alloy.

In general, Al-Si Alloys melts are also subjected to a "modifier" such as strontium (Sr) or Sodium (Na), the naturally occurring acicular form of the eutectic silicon is converted or "modified" to fibrous form which is beneficial to the alloy properties, in particular, the ductility. Apart from chemical modification, the Si particle size and morphology can also be improved during solution treatment [4]. Among the aluminum alloys, Al-Si alloys are known for their good castability and mechanical properties. The addition of Mg, Cu, and Sr makes the alloys heat-treatable, providing the means to enhance their properties with the use of appropriate of an Al-Si cast alloy are mainly determined by its cast structure and microstructure characteristics such as the grain size, shape and distribution of the eutectic silicon particle, as well as the morphologies and amounts of intermetallic phases present. These parameters are completely changed after heat treatment, which, in turn, influence the resultant mechanical properties [5].

II. LITERATURE REVIEW

The hardness of a surface of the material is, of course, a direct result of inter-atomic forces acting on the surface of the Material. We must note that hardness is not a fundamental property of a material, however, but rather a combined effect of compressive, elastic and plastic properties relative to the mode of penetration, shape of penetrator, etc. Hardness seems to bear a fairly constant relationship to the tensile strength of a given material and thus it can be used as a practical non-destructive test for an approximate idea of the value of that property and the state of the metal near the surface. All hardness tests are made on the surface or close to it. We may note that in mechanical tests the bulk of material is involved. Hardness of materials is of importance for dies and punches, limit gauges, cutting tools, bearing surfaces etc.

Hardness measurement can be defined as macro, micro or nano scale according to the forces applied and displacements obtained. Measurement of the macro-hardness of materials is quick and simple method of obtaining mechanical property data for the bulk material from a small sample. It is also widely used for the quality control of surface treatments processes. However, when concerned with coatings and surface properties of importance to friction and wear processes, for instance, the macro-indentation depth would be too large relative to the surface-scale features. Where materials have a fine microstructure, are multi-phase, non-homogeneous or prone to cracking, macro-hardness measurements are appropriate.

Micro hardness is the hardness of a material as determined by forcing an indenter such as a Vickers indenter into the surface of the material under 50 to 1000 gm load. Usually, the indentations are so small that they must be measured with a microscope. Capable of determining hardness of different micro constituents within a structure, or measuring steep hardness gradients such as those encountered in case hardening [6].

The standard test methods according to the American Society Testing and Materials (ASTM) available are, for instance, ASTM E10-07a (Standard test method for Brinell hardness of metallic materials), ASTM E18-08 (Standard test method for Rockwell hardness of metallic materials) and ASTM E92-41 (Standard test method for Vickers hardness of metallic materials). These hardness testing techniques are selected in relation to specimen dimensions, type of materials and the required hardness [7].

III. EXPERIMENTAL DETAILS

Al-Si alloy (A413) and intermetallic alloys used in the present work were obtained from Mechanical Research and Development Laboratory of our Institute, and the chemical compositions of the same are given in Table 1.

Alloy	Composition (Wt%)											
Composition	Si	Cu	Mg	Fe	Mn	Zn	Pb	Sn	Sr	Ti	В	Al
A 413	12.5	0.10	0.10	0.60	0.50	0.10	0.10	-	-	0.20	-	Bal
Al-5%Al ₃ Ti	0.15	-	-	0.20	-	-	-	-	-	5.02	-	Bal
Al-3%AlB ₂	0.15	-	-	0.16	-	-	-	-	-	-	2.83	Bal
Al-3%TiB ₂	0.15	-	-	0.16		-	-	-	-	1.00	2.28	Bal
Al-10% Al ₄ Sr	0.01	-	-	0.16	-	-	-	-	10.0	-	-	Bal

Table 1 Chemical Compositions of the reinforced intermetallic alloys

The base metal A413 added to the induction furnace where the melt held at 720 °C. The Degassing agent Hexachloro ethane (C2Cl6) used to remove the hydrogen gas bubbles from the molten A413, the overall reaction will be, $C2H6 + 6Cl2 \rightarrow C2Cl6 +$ 6HCl. The slag formed above the molten metal is removed. Ti, B & Sr were added to the molten A413 in the form of master alloys. Titanium and boron elements assist in finer grain refinement and Strontium assist in modification of base metal A413. The base metal along with master alloy are stirred continuously to blend well. The Cover Flux (40% NaCl + 40% KCl + 20% NaF) is added to the molten alloy in order to reduce the melt oxidation, minimize penetration of the atmospheric oxygen, absorb non-metallic inclusions suspended in the melt, keep the furnace wall clean from the buildup of oxides, decrease the content of aluminum entrapped in the dross, remove hydrogen dissolved in the melt and modify silicon inclusions in silicon containing alloys. Now the molten metal from the crucible poured into the mold. When the alloy metal is cooled, it is removed from the mold. Now the specimens are polished by both the dry and wet polishing types using the Double Disk Polishing Machine.

Table 2Test specimen identification of Alloys used.							
Specimen composition (Optimized)	Specimen code						
A413 (As cast)	1A						
A413 + Al-5% Al ₃ Ti	2A						
A413 + Al-3% AlB ₂	3A						
A413 + Al-3% TiB ₂	4A						
$A413 + Al-10\% Al_4Sr$	5A						
A413 + Al-3% TiB_2 + 10% Al ₄ Sr	6A						

Methods used for heat treatment (optimized)

- 1. By hot steam ejection for 30 min and 60 min.
- 2. Heat treated by muffle furnace at 50 °C for 60 min and 120 min.

IV. RESULT AND DISCUSSIONS

Hardness Test results without heat treated (As cast)

Fig. 1 shows the hardness number of the alloys without heat treated (as cast).





The investigation reviles that the hardness increases linearly with the addition of inter metallic particles, as in the case of 3A increase in hardness can be seen as the addition of inter boron metallic particles influences on the hardness as boron atoms migrate in the crystal lattice and the number of dislocations decreases,



Figure 2b VHN heat treated by steam for 60 min.

As shown in the fig, 2a and 2b the hardness number in dependent of addition of inter metallic particles. In case of heat treated by steam for 30 min, alloy 5A seems to be hardened compared to the other alloys. Sr particles present in 5A, modifies the silicon with effect of redistributing and eradication. The investigation as seen in Fig 2b the Alloy 3A posses good hardness as inter boron metallic particles influences on the hardness as boron atoms migrate in the crystal lattice and the number of dislocations decreases,



As seen from the above fig 3a and 3b, the alloys with heat treated 50 °c for 60 min and 120 min were investigated, noticed that alloy 4a hardness increases drastically for 120 min since Ti and B reduce the defect called dislocation thus forming recrystallization to form a new strain free grain nucleate and grow to replace those deformed internal stresses.

V. CONCLUSIONS

- Hot steam ejection for 30 minutes, Hardness increased from 70.16 HV to 76.06 HV
- Heated at 50 °C for 120 min, Hardness increased from 71.94 HV to 73.72 HV
- Heated in Palm oil at 150 ^oC for 60 min, Hardness increased from 73.72 HV to 74.49HV
- Hot steam ejection for 60 min, Hardness value increased from 72.16 HV to 78.40 HV
- Heated at 50 °C for 120 min, Hardness value increased from 71.28 HV to 75.13 HV
- Hot steam ejection for 30 minutes, Hardness value increased from 73.01 HV to 74.18 HV
- Hot steam ejection for 60 min, Hardness value increased from 74.18 HV to 75.57 HV
- Heated at 50 °C for 120 min, Hardness value increased from 70.61 HV to 79.29 HV

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