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Studies of the Mechanical Properties of Age-hardened Al-Si-Fe-Mn Alloy

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Abstract: Study has been made on the mechanical properties upon age-hardening treatment to Al-Si-Fe-Mn (Aluminium- Silicon- Iron- Manganese) alloy. The produced alloys consist of varying manganese content from 0.1to 0.5 percent with constant Si-Fe composition and Al as the dominant constituent. As-cast alloys were produced and also age-hardened. There mechanical properties; Tensile properties, Hardness and Impact strength were investigated according to standard procedures. From the results, addition of Mn to the alloy increased the tensile properties and hardness subject to 0.4 percent for both the as-cast and age-hardened conditions. While the impact energies upon addition of Mn decreased with the age-hardened samples having better mechanical properties than the as-cast one.

Key words: Age-hardening, Al-Si-Fe-Mn alloy, As-cast, Dominant constituent, Mechanical properties.

INTRODUCTION

Aluminium alloys are widely used in the production of automotive components, buildings and constructions, containers and packaging, marine, aviation, aerospace and electrical industries because of there light weights, corrosion resistance in most environments or combination of these properties(Allen. D.K. 1983; Rajan TV and Sharma C.P 1988; Avner. S.H. 1974). Aluminium based alloys also have high thermal conductivity and low coefficient of linear expansion values and based on these two properties, they can be forged to the desired shapes at elevated temperatures and then solution treated and aged hardened to obtain desired microstructures and excellent mechanical properties (Nwajagu.C.O 1994; Rollason E.C. 1986). Al-Si-Fe as a ternary alloy provides good combination of cost, strength, corrosion resistance, together with high fluidity and freedom from hot shortness (Metals Handbook 1979). The compositional specification of these alloys rests mainly on the iron, silicon and manganese contents, while addition of manganese alone improves the toughness of the alloy (Gayle. F.W and Vadersande. J.B. 1986). Iron also increases strength and hardness, reduces tendency to hot cracking while Silicon improves the fluidity of the molten metal as well as its castability and mechanical properties (Datsko, J 1966). Precipitation hardening is the most commonly heat treatment process used in improving the mechanical properties of aluminium alloys. Works carried out on Al-Cu and Al-Si alloys (Markandeya R, *et al.*, 2004) showed that, age hardening through precipitation hardening strengthens them. Interactions of the various phases in the alloy systems during precipitation and how the interactions affect their mechanical properties have not been studied. Although in an earlier work by Madugu and Abdulwahab (Madugu, I.A. and Abdulwahab, M. 2007), the mechanical properties of Al-Si-Fe-Mn alloy in the as-cast condition has been studied. The work did not consider any heat-treatment on the alloy. Hence, the objective of this work which is to study the response of the alloy system to precipitation hardening (Age-hardening) heat treatment in terms of mechanical properties.

Theortical Consideration:

The presence of Si, Fe and Mn in aluminium causes various precipitates to form during solidification of the alloys (Allen. D.K. 1983). During the solidification of the alloys system, development of dendritic network, precipitation of AlFe-containing phase, eutectic reaction involving precipitation of Si and Fe containing phases and formation of complex eutectic phases containing $(Mn,Fe)Al_6$ and α(Al-Si-Fe-Mn) constituent (Rajan. TV and Sharma C.P 1988) do occur. The phases formed depend on the composition and cooling rates of the alloy system. The Manganese complexes are easily visible under the optical microscope because of their distinct grayish-white colour but the iron phase seem to be present in both needle (β) and Chinese script form (α) (Madugu, I.A. and Abdulwahab, M. 2007).

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Principles of Age Hardening of Aluminium alloys:

Heat treatment processes for increasing the strength and hardness of either wrought or cast aluminium alloys utilize the mechanism of precipitation hardening. One essential attribute of a precipitation hardening alloy system is a temperature and time dependent equilibrium solid-solubility characterized by decreasing solubility with decreasing temperature and then followed by solid-state precipitation of second phase atoms on cooling in the solidus region. These conditions are usually met by most aluminium equilibrium systems of heat-treatable types, such as the Al-Si and Al-Cu alloys etc (Ghosh. K.S, *et al.,* 2004). The first stage of precipitation can be made to occur at room temperature and this is called natural aging while subsequent precipitations can be accelerated by heating the alloy to slightly above the room temperature and then cooling in air which is referred to artificial aging. Precipitation heat—treatment for the purpose of increasing strength and hardness is a three step process.

The first step is the solution heat-treatment that involves dissolution of soluble phases followed by quenching for the development of super-saturation and then aging which is the precipitation of solute atoms either at room temperature (natural aging) or elevated temperatures (artificial aging) (Ghosh. K.S, *et al.,* 2004).

Solution Heat-treatment:

In order to take the advantage of the precipitation hardening reaction, it is necessary first to produce a solid solution. Production of a solid solution consists of soaking the Aluminium alloy at a temperature sufficiently high and for such a time so as to attain an almost homogeneous solid solution. The soaking time is required to achieve a satisfactory degree of dissolution of the undissolved or precipitated soluble phase constituents and for attainment of a reasonable degree of homogeneity (Markandeya R, *et al.,* 2004).

Quenching:

Quenching is carried out to avoid slow cooling which may result in the precipitation of phases that may be detrimental to the mechanical properties or to the corrosion resistance of the alloys. For these reasons solid solutions formed during solution heat-treatment are quenched rapidly without interruption to produce a supersaturated solution at room temperature (Ghosh. K.S, *et al.,* 2004).

Ageing:

After the formation of a super saturated solid solution then the precipitation of the solute atoms (aging) followed which is usually accomplished naturally or artificially Precipitation heat-treating is used to impart high strength and hardness to Aluminium alloys. Generally artificial aging imparts higher strength and hardness values to Aluminium alloys without sacrificing other mechanical properties and also improves the resistance of these alloys to exfoliation and stress- corrosion cracking (Metals Handbook 1979; Metals Handbook 1979; Datsko, J 1966).

MATERIALS AND METHOD

Materials:

The materials used for this research for the production of Al-Si-Fe-Mn alloy systems includes high purity aluminum obtained from Northern Cable Company NOCACO Kaduna and ferroalloys (FeSi, FeMn), etchants, silica sand and bentonite, moulding boxes from National Metallurgical Development Center (NMDC) Jos.

Equipments:

The following equipment were used, Muffle electrical resistance furnace, Denison impact tester, Rockwell Hardness B Scale machine, Tinius Olsen tensile testing machine, Polishing machine, Metallurgical microscope.

Methods:

Six different compositions of alloys were produced in which the amounts of Mn in the alloys were varied from 0.1 to 0.5% while the percentages of Si and Fe were kept constant (Table 1). Each composition was melted separately in Alumina crucible. The melting was done using a muffle resistance Furnace that was allowed to heat to 750^0C before the crucible was removed and other alloying elements (ferroalloys) added. Then the crucible was returned back to the furnace for further 30 minutes during which the furnace temperature was raised to 800^0C for superheat to occur then 0.01%NaCl was added and stirred thoroughly before pouring into the mould. The cast samples were machined to standard tensile, hardness and impact test specimens.

Heat Treatment:

The machined samples were solution heat treated at temperature of 490^{0}C in an electric heat treatment furnace, soaked for six hours at this temperature and then rapidly quenched in warm water. The quenched specimens were then aged at 200^{0}C for six hours before cooling in air.

RESULTS AND DISCUSSION

Results:

The variation in the mechanical properties against %Mn additions of the as-cast obtained from Madugu and Abdulwahab (Madugu, I.A. and Abdulwahab, M. 2007) and precipitation hardened specimens are given in Figures 1 - 3.

Table 1: The Chemical Composition of the produced alloys.

S/N	%Si	%Fe	%Mn	%Al
1	2.1	0.7	___	97.2
2	2.1	0.7	0.1	97.1
3	2.1	0.7	0.2	97.0
4	2.1	0.7	0.3	96.9
5	2.1	0.7	0.4	96.8
6	2.1	0.7	0.5	96.7

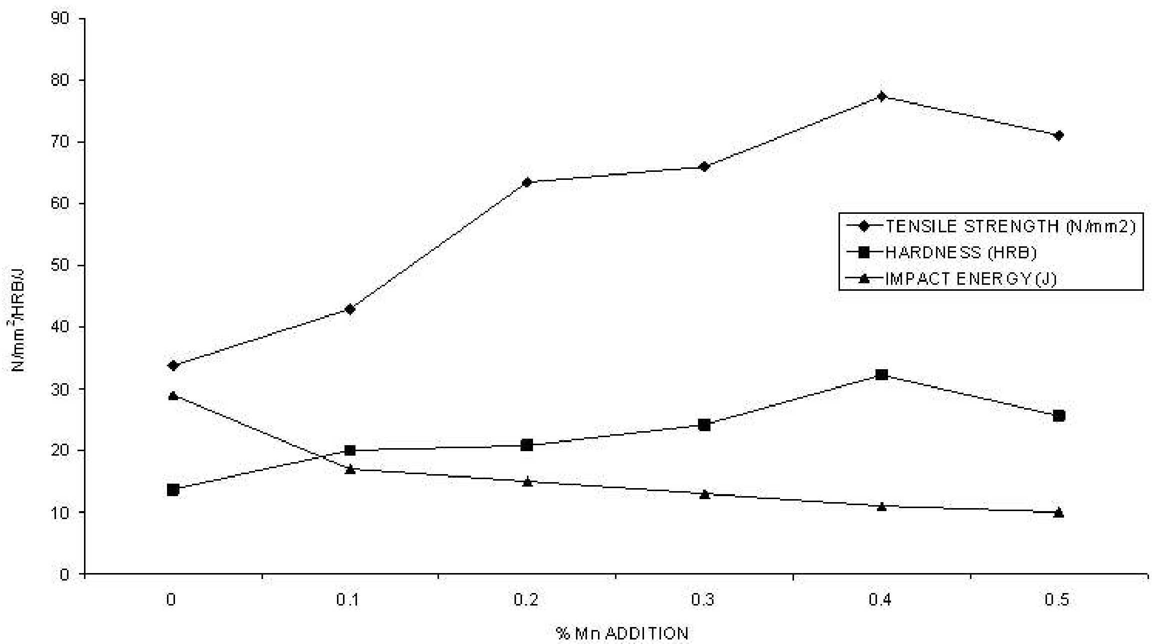

Fig. 1: Variation of Tensile Strength, Hardness and Impact Energy Against Percentage Mn Addition for As-cast Condition

Discussion:

From the results obtained in this research, it can be seen that the ultimate tensile strength (UTS) and the hardness of the alloys increase with increase in Mn additions for both the as-cast and age-hardened condition but dropped sharply at 0.5% for Mn additions (Figures 1-3). However, age-hardened alloys have higher UTS and hardness values. The explanation for the increase in the ultimate tensile strength and hardness as the percentage manganese increases up to 0.4% and then fell sharply at 0.5% Mn may be probably as a result of the formation of fine dispersoid of (Mn, Fe) Al_6 and α(Al-Si-Fe-Mn) constituents, and the manganese –rich precipitate nucleate preferentially and create a pinning action which inhibited the movement of the dislocations, hence increasing the strength and hardness of the alloys. This also agree with the statement that Mn increases strength either in solid solution or finely precipitated intermetallic phase and has no adverse effect on corrosion resistance. And that iron has a high solubility in molten aluminium and is therefore easily dissolved at all

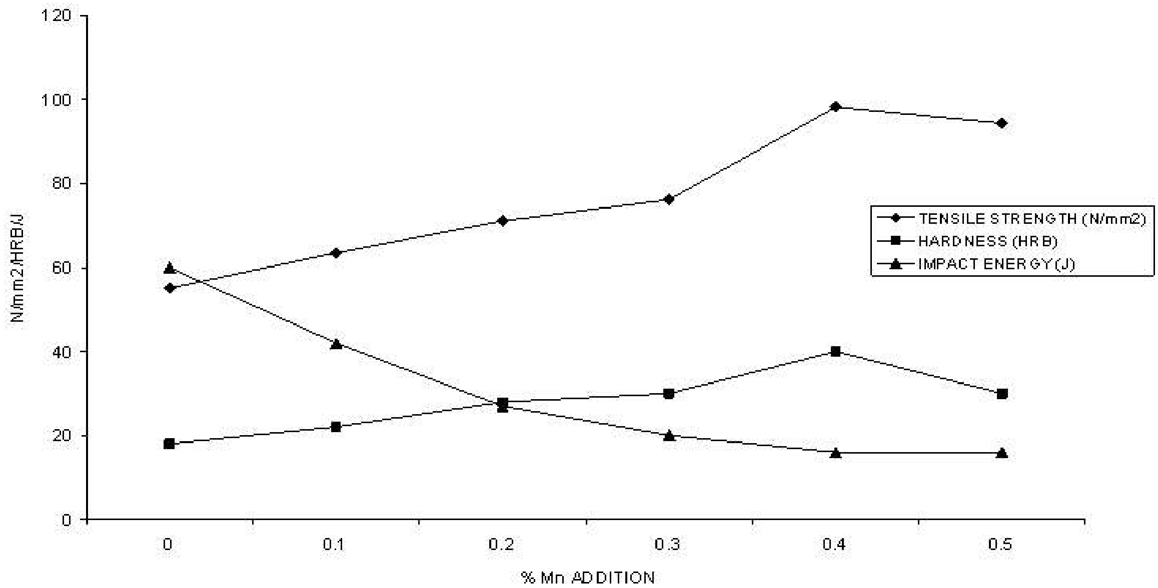

Fig. 2: Variaton of Tensile Strength , Hardness and Impact Energy Agaisnt Percentage Mn Addition for Age -Hardened Condition

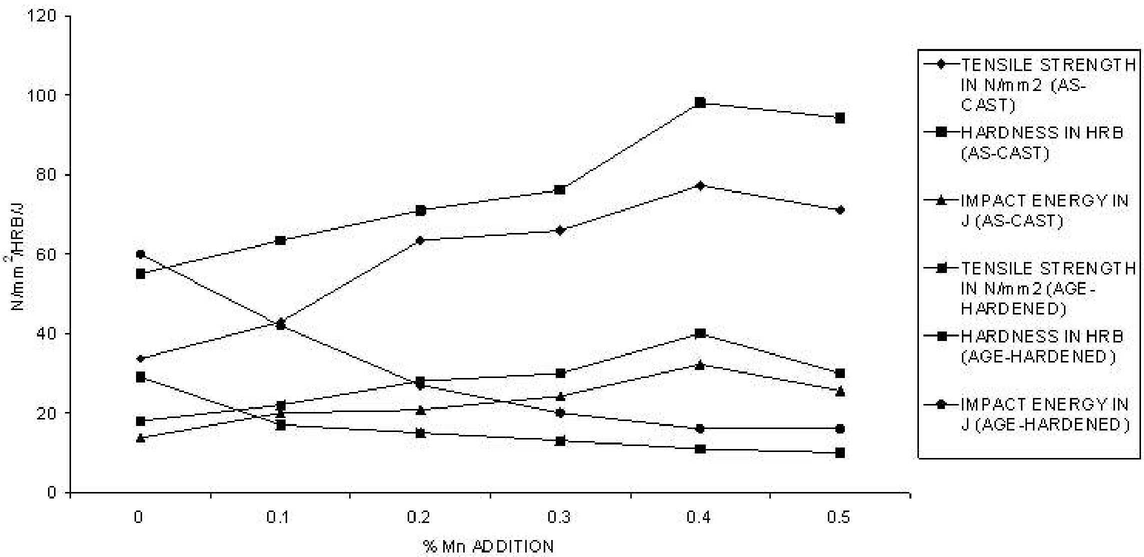

Fig. 3: Variaton of Tensile Strength , Hardness and Impact Energy Agaisnt Percentage Mn Addition for Both As-cast and Age -Hardened Conditions

molten stages of production and most of iron present in aluminium has an intermetallic second phase in combination with aluminium and often other elements (Internet link 2007). While the impact energy decreased for all percentages of Mn additions for both as-cast and age-hardened samples with the age-hardened having better impact properties than the as-cast (Figures 2 and 3).

However, after age-hardening the alloy the variation in the mechanical properties is in line with past researches that the effect of precipitation on mechanical properties are greatly accelerated by reheating the quenched material to about 100-200^{0}C and that a characteristic feature of elevated-temperature aging effects on tensile properties is that the increase in yield strength is more pronounced than the increase in tensile strength and at higher aging temperature the precipitate particles appear more ordered and strengthening by aging is a result mainly of interactions between dislocations and precipitates by shearing, with less contribution from the surrounding strains. Also ductility, as measured by percentage elongation, decreases (Internet link 2007; Internet link 2007; Hansen, V., *et al.*, 2004).

Conclusion:

The three mechanical properties (Hardness, Tensile Strength and Impact Energy) of the as-cast alloys increase after Age-hardening for all levels of manganese addition considered. However, beyond 4% Mn additions, the hardness and the tensile strength of the precipitation hardened alloys began to fall, while the impact energy generally decreases with increase in manganese additions. Also manganese addition beyond 4% decreases the amenability of the alloy (Al-Si-Fe) to Age-hardening. Therefore for attainment of optimum mechanical properties the manganese addition to this alloy should not be beyond 4% for both as-cast and Age-hardened alloys.

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