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Effects of Manganese Addition on Tensile Strength of AA6063 Alloy for Marine Application

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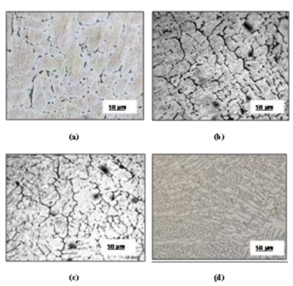
Graphical abstract



Abstract

AA6063 alloy is a common materials used in boat and ship construction due to its lightweight and good strength. However, its strength is lower than steel's strength. For that reason, an improvement in strength is needed. In this work, an attempt has been made to improve the tensile strength of AA6063 alloy by adding manganese (Mn) element. From 0.5 to 2.5 wt.% of Mn was added to AA6063 alloy and melted together before being cast into a cylindrical steel mould. The alloy was solutionised at 535°C for 6 hours and followed by water-quenching. The alloy was then artificially aged at 200°C for 5 hours and followed by natural aging for 14 days. Tensile tests were carried out according to ASTM E8M-03 procedures. The combination of artificial and natural aging has increased the ultimate tensile strength of all AA6063 alloys (with and without Mn). The ultimate tensile strength of the alloys increased with the increase of Mn content. An addition of 2.5 wt% Mn has increased the ultimate tensile strength of AA6063 alloy to 189.55 MPa after solution treatment and artificial aging followed by 14 days natural aging compared to as-cast AA6063 alloy which has the ultimate tensile strength of 61.33 MPa.

Keywords: AA6063 alloy; *manganese*; tensile strength; artificial aging; natural aging

Abstrak

Aloi AA6063 adalah bahan yang biasa digunakan dalam pembinaan bot dan kapal kerana ia ringan dan mempunyai kekuatannya yang baik. Walau bagaimanapun kekuatannya lebih rendah daripada kekuatan keluli. Oleh sebab itu kekuatan aloi AA6063 perlu dibaiki. Dalam kajian ini, suatu usaha untuk menambah baik kekuatan tegangan aloi AA6063 melalui penambahan unsur mangan (Mn) telah dilakukan. Sebanyak 0.5 hingga 2.5% berat Mn telah ditambah ke dalam aloi AA6063 dan dilebur sebelum dituang ke dalam acuan keluli berbentuk silinder. Aloi dirawat larutan pada 535oC selama 6 jam dan dilindap kejut di dalam air. Aloi kemudian dikenakan penuaan buatan pada 200oC selama 5 jam dan diikuti dengan penuaan tabii selama 14 hari. Ujian tegangan dijalankan merujuk pada prosedur ASTM E8M-03. Gabungan penuaan buatan dan penuaan tabii telah meningkatkan kekuatan tegangan muktamad semua aloi AA6063 (yang mengandungi Mn dan yang tanpa Mn). Kekuatan tegangan muktamad aloi meningkat dengan meningkatnya kandungan Mn. Penambahan 2.5 % berat Mn telah meningkatkan kekuatan tegangan muktamad aloi AA6063 kepada 189.55 MPa selepas rawatan larutan dan penuaan buatan diikuti dengan 14 hari penuaan tabii berbanding dengan aloi AA6063 tuangan yang mempunyai kekuatan tegangan muktamad 61.33 MPa.

Kata kunci: Aloi AA6063; mangan; kekuatan tegangan; penuaan buatan; penuaan tabii

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■1.0 INTRODUCTION

Manganese (Mn) is known as an important alloying element in aluminium alloys that contributes to uniform deformation [1]. It was found that as the Mn content increases over 0.5 wt % in aluninium alloys such as the 6xxx series alloys, both yield and ultimate tensile strength increase significantly without decreasing in ductility [1]. The addition of Mn up to 2 wt% to aluminium alloys can move their corrosion potential towards more anodic potential [2]. It was reported that the strength of the aluminium alloys increased gradually as the percentage of Mn increased due to the solid solution hardening in the Al-matrix [3]. Mn increases the alloy strength by promoting the formation of fine precipitate of intermetallics such as Mg_2Si. Mn combines with Fe, Si and Al to form α-$Al_x(Fe,Mn)_ySi_z$ phase that act as a nucleation sites for

Mg_2Si particles [4]. The presence of fine precipitate of Mg_2Si increases the alloy strength.

The 6xxx series alloy uses Mn to control grain size [5]. Abdulwahab [6] found that addition of Mn to the Al-Si-Fe-Mn Alloy increased the tensile strength to 0.4 percent for both the as-cast and age-hardened conditions. He suggested that the formation of fine dispersoid of (Mn, Fe) Al_6 and α (Al-Si-Fe-Mn) constituent, and the Mn–rich precipitate which created a pinning action to the movement of the dislocations, hence increasing the strength of the alloys.

The increase in grain boundaries because of finer grain sizes will provide greater obstacles to deformation thus increase the strength of the alloy [7]. Aging also leads to the formation Al-Mn intermetalic phases [8] that contributes to the increase of the alloy strength. Park & Nam [9] found that the Mn dispersoid in the aluminium alloy has increased the strength significantly without losing much elongation. This is due to the strengthening effect produced by pinning action of the dispersoid on dislocation glide and the enhancement effects in elongation caused by homogenization of slips [9].

Corrosion-resistant Al-alloys such as AA6063 are commonly used in marine applications [10]. They have good mechanical properties as well as heat treatable and weldable due to the presence of magnesium and silicon as the main alloying elements. American Bureu of Shipping (ABS) and the American Society for Testing and Material (ASTM) have unified their requirement on AA6063 alloys for shipbuilding with solution heat treatment and artificial aging(T6)[11]. However, the strength of AA6063 alloy is lower than that of steels. For that reason, an improvement in strength is needed.

Artificial aging treatments are commonly applied to heat-treatable aluminium alloys to obtain a better mechanical property. Furthermore, small additions of Mg for example, 0.4 wt % Mg in the Al alloy has increased the response of the alloy to artificial aging, thereby increasing the achievable tensile strength [12]. The aim of this study is to investigate the effect of manganese additions on tensile strength of as-cast as well as artificially and naturally aged AA6063 alloys.

2.0 MATERIALS AND METHODS

In this work, AA6063 alloy is used as the starting material. The chemical composition of the alloy is shown in Table 1.

Table 1 Chemical composition of AA6063 alloy (weight %)

Si	Fe	Cu	Mg	Cr	Zn	Ti	Co	Al
0.53	0.25	0.02	0.44	0.01	0.28	0.03	0.01	Balance

The composition was then modified with the addition of 0.5 to 2.5 wt% of Mn. The amount of Mn used was based on a report that Mn content over 0.5 wt % in aluminium alloys, increase both yield and ultimate tensile strength [1].

All alloys were prepared by melting at 800°C with a holding time of 10 minutes. The melt was cast into a cylindrical steel mould of 14 mm in diameter. The as-cast alloys were machined to produce tensile specimens in accordance to the ASTM E8M-03. Figure 1 shows the dimensions of the tensile specimen.

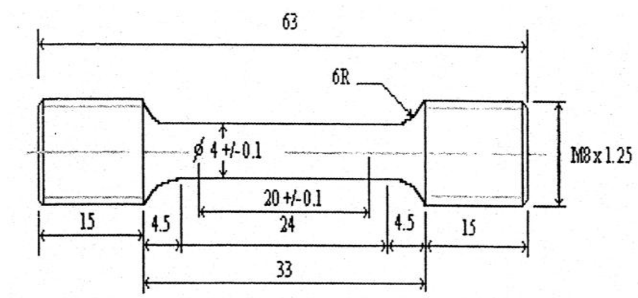

Figure 1 An ASTM-E8M round tensile specimen drawing (all dimensions are in millimetres)[13]

The specimens were then solutionised at 535°C for 6 hours and water-quenched to room temperature. The specimens were then subjected to an artificial aging at 200°C for 5 hours [14] and followed by natural aging for 14 days [15].

Tensile tests were carried out by using an Universal Test Machine, Instron 9567 with load of 3 tons in accordance to the ASTM E8M-03. Uniaxial tensile stress was applied with a speed of 1 mm/min.

For microstructural study the specimens were mechanically ground using SiC papers and polished with diamond spray to 6 micron surface finish and followed by etching in Keller's reagent. The microstructural observation was carried out under an optical microscope model Axiocam Carl Zeiss Vission 4.4.

3.0 RESULTS AND DISCUSSION

The ultimate tensile strength of as-cast AA6063 alloy without Mn was found to be 61.33 MPa and increased to 127.64 MPa when added with1.0 wt % Mn (Figure 2). The increase was believed to be due to the decrease in the grain size (Figure 3a & b). The increase in ultimate tensile strength is not significant when the Mn content is higher than 1.0 wt.%. This is because the Mn additions of more than 1.0 wt.% did not result in significant changes in grain size (Figure 3b & c). Similar observation was also reported by Abdulwahab [6] where the addition of Mn to the Al-Si-Fe-Mn alloy has increased tensile strength of the alloy to 0.4 percent for both the as-cast and age-hardened conditions. His suggestion that the formation of fine dispersoid of (Mn, Fe)Al_6 and α(Al-Si-Fe-Mn) constituent, and the Mn–rich precipitate which lead to a pinning action to the movement of the dislocations, hence increasing the strength of the alloys[6] is also applicable in explaining our findings where the strength of AA6063 alloy increased with the increase in Mn content.

After solution treatment, artificial and natural aging, the ultimate tensile strength of this alloy was found to increase from 154.52 MPa without Mn, to 189.55 MPa with 2.5 wt% Mn (Figure 2). The increase in ultimate tensile strength is due to grain refinement (Figure 3). The increase in grain boundaries because of finer grain sizes will provide greater obstacles to deformation thus increase the strength of the alloy. Aging also lead to the formation Al-Mn intermetalic phase [8] that contributed to the increase of the AA6063 alloy strength. The increase in strength for heat-treated AA6063 alloy containing Mn may be contributed also by the Mn dispersoid formed in the alloy which produced strengthening effect by pinning action on dislocation glide [9].

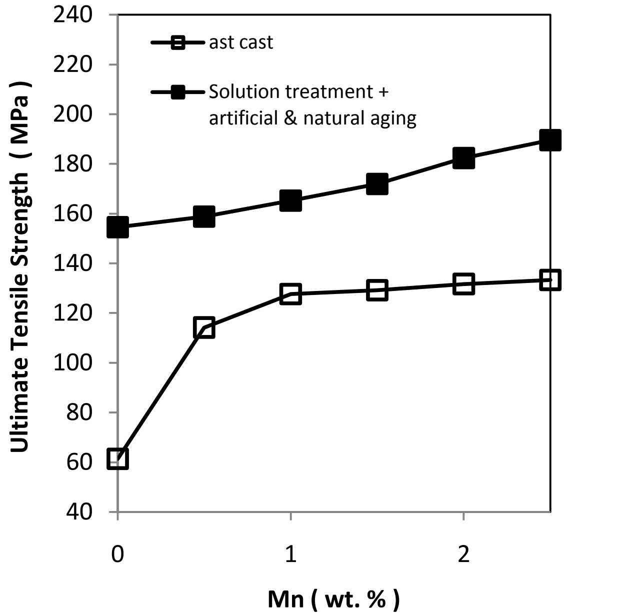

Figure 2 Effect of Mn additions on the ultimate tensile strength of AA6063 alloy

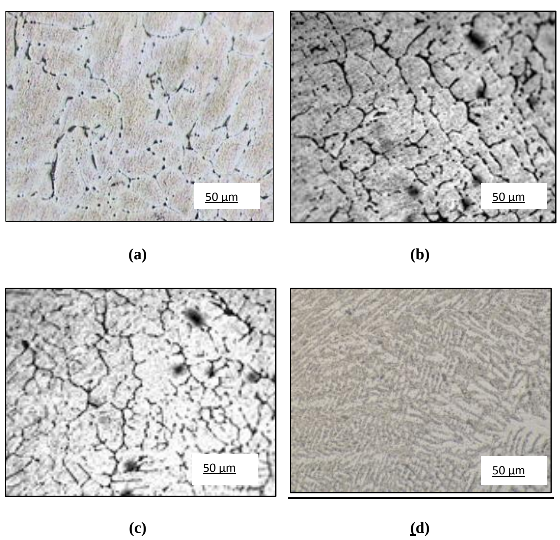

Figure 3 The microstructures of AA6063 alloys (a) as-cast without Mn, (b) as-cast with 1 wt% Mn, (c) as-cast with 2.5 wt% Mn and (d) with 1 wt %Mn after solution treatment, artificial and natural aging

4.0 CONCLUSIONS

The addition of Mn can improve the strength of AA6063 alloy. The ultimate tensile strength of AA6063 alloy increases with Mn content. The increase in strength is mainly due to grain refinement. AA6063 alloy containing 2.5 wt% Mn which has been subjected to solution treatment and artificial aging and followed by 14 days natural aging has ultimate tensile strength of 189.55 MPa whereas as-cast AA6063 alloy has the ultimate tensile strength of 61.33 MPa.

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