Effect of Mangan Content on Mechanical Properties and Corrosion Behavior of As Cast Fe-7.5Al-0.6C Alloy

By Ratna kartikasari

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Effect of Mangan Content on Mechanical Properties and Corrosion Behavior of as Cast Fe-7.5Al-0.6C Alloy

Ratna Kartikasari

Department of Mechanical Engineering,
"Nasional" College of Technology, Jl. Babarsari No.1, Caturtunggal, Depok, Sleman, Yogyakarta, Indonesia 55283
E-mail: kartikafajar@yahoo.com

Abstract

Effect of Mn content on mechanical properties and corrosion behavior of Fe-7.5Al-0.6C alloys in the as cast condition have been studied. Mechanical properties have been investigated by using tensile test, Vickers hardness test, impact test, scanning electron microscope and XRD. Corrosion test performed with 3 electrode cell polarization method in 0.5% NaCl media. The alloys were prepared by an induction furnace under an argon atmosphere. The results showed that the mechanical properties such as the ultimate tensile test (UTS) and elongation of these alloys were in the range 608.9-885.07 MPa and 21.35-60.62% respectively. The hardness, the Charpy impacts, and the corrosion rate of these alloys were in the range of 209-225.3 VHN, 52.8-70.2J and 0,016-0,075 mm/y respectively. Increased levels of Mn also lowers the corrosion rate of the as cast Fe-Al-C alloy in a 0.5% NaCl solution. Corrosion rate of this alloy is in the range of 0.016 to 0.075 mm/yr.

Keywords: as cast Fe-Al-C alloys, mechanical properties, corrosion behavior

1. INTRODUCTION

Fe-Al-C alloys are being developed for elevated temperature structural application for up to 873 K [1]. They also provide potential replacement for the more expensive stainless steel alloys such as AISI 304, 310 and 316 containing strategic elements like nickel and chromium [2]. However, poor ambient temperature ductility, poor toughness and poor creep resistance of these binary Fe_3Al alloys have limited their structural applications [3]. Hence, there have been a number of attempts to improve these properties by various ternary additions of Cr, Mo, Ti, Ni, Si, Nb, Ce and Zr [4–5]. Further it has also been shown that reducing aluminum content (8-10%) and increasing C (0.8-1.1%) resulted in improved ductility [6-7].

Addition of small quantities of Zr and Ce to Fe–10.5Al–0.8C (wt-%) (lower aluminum and higher carbon) alloy resulted in a significant improvement in tensile ductility and that addition of Nb has resulted in improvement in strength [8]. Addition of Ti has resulted in poor tensile and creep properties [9].

Addition of W to the base alloy Fe–10.5Al–0.7C resulted in a marginal improvement in yield strength at room temperature as well as yield strength and creep properties at 873 K. Addition of Mn to base alloy also resulted in greater improvement in yield strength and tensile elongation at room temperature. The improvement in yield strength owing to addition of W and Mn may be attributed to solid solution strengthening of matrix (Fe–Al, α) and the precipitates ($Fe_3AlC_{0.5}$). The reasons for the higher ductility along with higher strength when Mn is added to the base alloy are being investigated. It has also been noticed that the addition of Mo has resulted in significant improvement in yield strength at room temperature as well as yield strength and creep properties at 873 K [9].

The manganese addition makes the Fe–Al system austenitic, and its mechanical properties were improved. The effect of manganese on corrosion resistance is detrimental. Manganese with a low passivity coefficient forms an unstable manganese oxides film, decreases the open circuit potential and increases the corrosion current density [10]. Manganese interacts with sulfur in stainless steels to form manganese sulfides. The morphology and composition of these sulfides can have substantial effects on corrosion resistance, especially pitting resistance [11]. Besides β-Mn phase can cause embrittlement [12]. The effects of silicon addition on the mechanical properties, corrosion resistance and high-temperature oxidation resistance of Fe–Mn–Al–C alloys have been presented by many authors [13].

2. EXPERIMENTAL PROCEDURE

Five alloys with nominal compositions listed in Table 1 were prepared by an induction furnace under an argon atmosphere. Fe-Mn medium C, mild steel scrap, high purity aluminum, and Fe-C were used as raw materials. Thirty five kilograms of molten metal is poured into ingot molds measuring 40 mm x 40 mm x 200 mm. The ingot was cut using bimetallic band saw blade to make the test specimens. Tensile test specimens were cut based on JIS 2201 standard. The Vickers hardness specimens were made on longitudinal sections of ingots. The Impact Charpy specimen of 3mm x 10mm x 55 mm with 2mm v-notch based on JIS Z 2242 standard. Corrosion specimens were made based on ASTM G 30 (14 mm in gauge diameter and 3 mm in gauge length).

Table 1. Chemical composition (wt-%) of the alloys tested

Alloys	Al	Mn	C	Si	P	S	Fe
A	7.50	5.02	0.55	0.62	0.02	0.01	Bal.
B	7.45	9.97	0.56	0.62	0.01	0.03	Bal.
C	7.55	14.95	0.55	0.60	0.01	0.01	Bal.
D	7.50	20.04	0.61	0.56	0.01	0.02	Bal.
E	7.54	25.05	0.60	0.65	0.02	0.03	Bal.

The surface of the corrosion specimens were mechanically polished with abrasive paper up to 1200 grit, after surface finishing. The last mechanical polishing was done with 0.5 μm alumina paste. The corrosion measurements were carried out with three-electrode polarization in 0.5% NaCl. The corrosion type and the morphology of the oxide scale were determined by optical and scanning electron microscope (SEM). Corrosions products were examined using EDS/EDAX.

3. RESULT AND DISCUSSION

Mechanical Properties

Figure 1 shows that the Fe-7.5Al-0.6C alloy has a tensile strength of 595.33 MPa. The addition of 5% Mn in this alloy led to an increase in tensile strength of 2.3% so that the Fe-7.5Al-5Mn-C alloy has a tensile strength of 608.89 MPa. The addition of 10% Mn increases the strength of 16.7%, up to the addition of 25% Mn increase in tensile strength reached 48.67%. The addition of Mn in the Fe-7.5Al-0.6C alloy system cause an increase in tensile strength is significant. As has been reported that the addition of 2 wt% Mn in the Fe-10.5Al-0.7C alloy system increase the tensile strength of 8.25% and 44.4% strain [9] and the Mn content of up to 10% in the Fe-Al-C alloy lead alloy duplex structure α / γ [14].

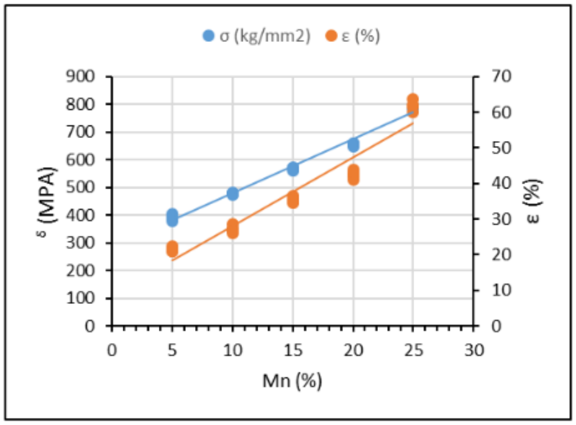

Fig. 1. Tensile strength and elongation of the Fe-7.5Al-xMn-0.6C alloy

Overall the tensile strength of the Fe-7.5Al-xMn-0.6C alloy is in the range from 608.89 to 885.07 MPa, where the higher levels of Mn higher tensile strength (Figure 1). This is due to the addition of Mn in the alloy causes the austenite structure stable at room temperature, and the higher levels of Mn austenitic structure is formed more and more.

Strengthening mechanism by Mn and Al in the Fe-7.5Al-xMn-0.6C alloy system can be described as follows, Mn in Fe crystal system occupies a position equivalent to Fe. The crystal system is FCC (γ). Al element occupies the corner points of cubic crystals while Fe and Mn atoms occupy the central point of cubic crystal system (γ '). Changes in the crystal structure of disordered γ becomes γ 'ordered lead to an increase in tensile strength significantly. At levels below 15% Mn at most γ 'ordered to be transformed into a phase κ (Fe, Mn) 3AlC. While the level of 25% Mn has become austenitic microstructure (γ) is perfect. The formation of a single phase of these elements causes stress field interaction between atoms dissolved with dislocation, so requiring greater mechanical energy for plastic deformation [15].

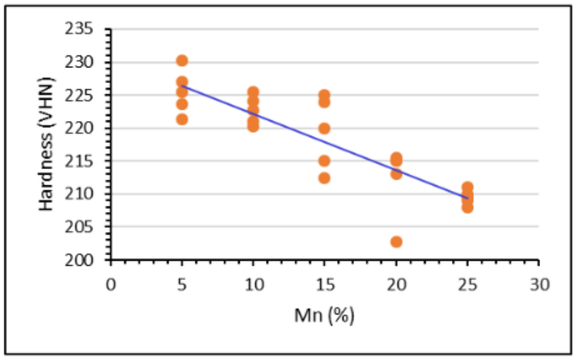

Fig. 2. Hardness of the Fe-7.5Al-xMn-0.6C alloy

Curve of hardness test results of the Fe-7.5Al-0.6C alloy at various levels of Mn are presented in Figure 2. Increased levels of Mn in the Fe-7.5Al-xMn-0.6C alloy causes no significant decrease in hardness. The decrease ranged from 1.5 to 3.3% of hardness occurs in elevated levels of Mn range of 5%, 10%, 15%, 20% to 25%. The highest hardness occur at 5% Mn concentration_with hardness values of 225.5 VHN. The hardness values decreased with higher levels of Mn to the lowest hardness, that occurs in 25% Mn content in the amount of 209.5 VHN (16% decrease). The hardness values continue to decline with higher levels of Mn to the lowest hardness that occurs in 25% Mn content in the amount of 209.5 VHN. The hardness values decreased with higher levels of Mn. The lowest hardness (VHN 209.5) occurred in 25% Mn. If the terms of the structural changes that occur in the range of elevated levels of Mn increased number of austenite structure formed causes impairment of hardness, it is equivalent to a decrease in tensile strength caused by increased levels of Mn in the alloy. Mn atoms occupy the Fe atoms to shift the position of Al atoms in the Fe-7.5Al-xMn-0.6C alloy system, that causes the lattice density is reduced so that the level of hardness decreased [15]. However, because of the size of the Mn atoms (1.79 Angstroms) is much smaller than the size of atoms of Al (1.82 Angstroms) and is closer to the size of the Fe atoms (1.72 Angstroms), the rate of decline is relatively small (not significant).

The addition of Mn in the Fe-7.5Al-0.6C alloy system resulted in a significant increase in toughness up to 2.35 J / mm2 at 5% Mn. Figure 3 shows that toughness continued to increase with increasing 10%, 15%, 20% Mn content and reached the highest at 25% Mn content is equal to 3.3 J / mm2. As reported by previous researchers that the addition of Mn to the Fe-7.5Al-xMn-0.6C alloy system increases the strength and toughness significantly [8]. Increased strength followed by a significant increase in ductility resulted in an increase in very high toughness. This is caused by the change into the austenitic microstructure. This phenomenon is also supported by the shape of the fracture surface specimen impact of the Fe-7.5Al-xMn-0.6C alloy (Figure 4). At the level of 5% and 10% Mn fracture surface impact specimen still looks brittle, with increased levels of Mn (15%) increasing the toughness shown that the fracture surface shows the deformation / reduce cross-section (necking). Substitution of Mn in Fe crystal system causes a significant increase in toughness. The big difference in the distance between atoms (lattice) causes the movement of atoms in the material when it receives the load becomes more freely. Mechanically seen the value of toughness, ductility and a higher strain.

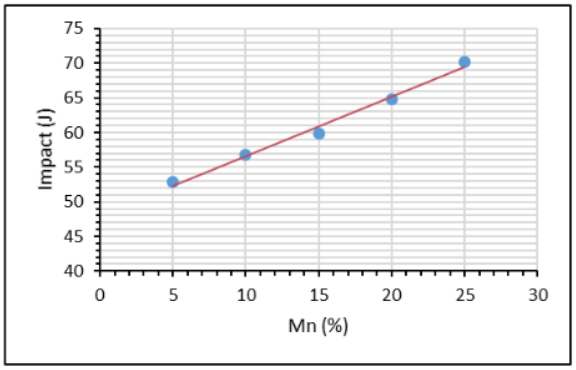

Fig. 3. Impact toughness of the Fe-7.5Al-xMn-0.6C alloy

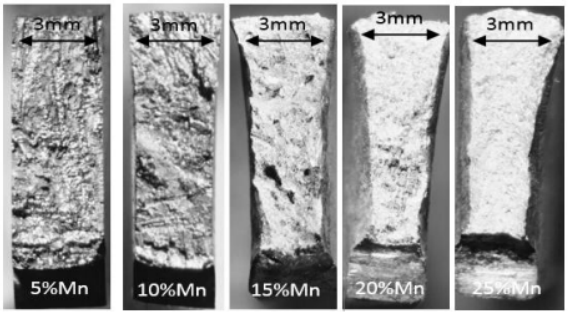

Fig. 4. Fracture surface impact test specimen of the Fe-7.5Al-xMn-0.6C alloy

Corrosion Behavior

Polarization curve of Fe-Al-C alloy with Mn added in 0.5% NaCl solution showed passivation characteristics on all levels of Al (Figure 5). This phenomenon is caused by the formation of Al_2O_3 compounds due to contact of Al with oxygen from the environment on the surface of the alloy. This compound is self-repairing Al_2O_3 as the conventional stainless steel [16] with the compact characteristics which require a continuous layer of 10% Al [17]. Passivity will increase with increasing Al content up to 12% [18], whereas the corrosion resistance of the alloy depends on the stability of this layer.

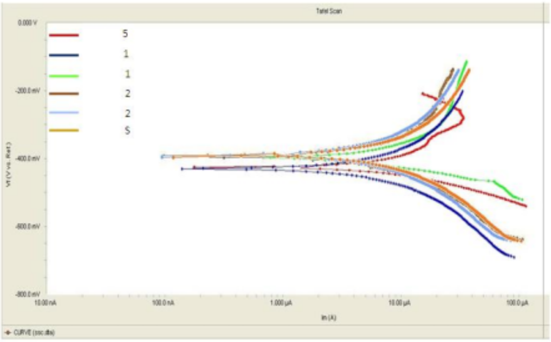

Fig. 5. Polarization curve of the Fe-7.5Al-xMn-0.6C alloy in 0.5% NaCl solution

Fe-Al-Mn-C Alloys have a corrosion rate in the range of 0.016 to 0.075 mm/yr in the 0.5% NaCl, with a tendency corrosion rate decreases with higher levels of Mn in the alloy (Figure 6). As Ni in conventional stainless steels, addition Mn to Fe-Al-Mn-C alloys play a role in increasing the strength and toughness, Mn elements also play a role in stabilizing the structure of austenite at room temperature and also play a role in improving the corrosion resistance of the alloys. According to The Corrosion Resistance Level Table [19] corrosion rate of up to 20% Mn content the Fe-Al-Mn-C alloys is very well category, while 25% Mn levels is included in outstanding category. Lowest corrosion rate of the Fe-Al-Mn-C alloys occurred in 25% Mn content is equal to 0.016 mm/yr. It is lower than the rate of corrosion of stainless steel SS 304 is equal to 0.025 mm/yr. Corrosion rate, from 5% to 25% Mn content is decrease sharply, reaching 78.67%.

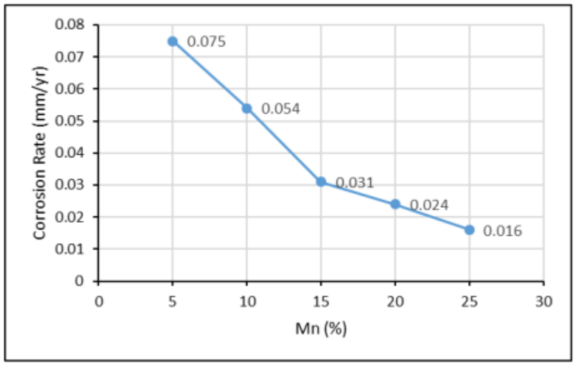

Fig. 6. Corrosion rate of the Fe-7.5Al-xMn-0.6C alloy

4. CONCLUSION

Increased levels of Mn in the Fe-7.5Al-0.6C alloys increases the tensile strength, strain, hardness and toughness. Increased levels of Mn also lowers the corrosion rate of the as cast Fe-Al-Mn-C alloy in a 0.5% NaCl solution. Corrosion rate of this alloy is in the range of 0.016 to 0.075 mm/yr.

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