EFFECTS OF SCANDIUM ADDITION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AA 7075 ALUMINIUM ALLOY

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Abstract: *The most attractive properties of aluminum and its alloys which make them suitable for a wide variety of applications are their light weight, appearance, frabricability, strength, and corrosion resistance. Among aluminium alloys AA7075 alloy has many attractive properties compared to other alloy it is economical and versatile to use this is the reason it is very widely used in the aerospace, automobile and other industries. AA7075 aluminum alloys are important structural materials due to their high strength and increased strength to weight ratio. The effects of Sc addition on the microstructure and mechanical properties of the AA7075 wrought zinc alloy were investigated by using optical microscope, scanning electron microscopy, and tensile testing. The experimental results show that a minor Sc addition to AA7075 alloy has an obvious effect on the refinement of the microstructure of the AA7075 alloy. During casting, incomplete dynamic recrystallization occurs in all the alloys, and the recrystallized grains become much finer with increasing Sc addition. The ultimate tensile strengths of AA7075 evidently increase with the addition of Sc, but the elongations decrease. The AA7075 alloy with 0.23% (weight fraction) Sc addition is found to have the tensile strength of about 468.8 MPa and the yield strength of about 324.3 MPa. Further by T6 tempering heat treatment, the tensile strength of the alloy containing 0.23% Sc is increased to 485.8 MPa and yield strength 335.49 Mpa.*

Key words: *AA 7075 alloy, Grain refinement, Tensile properties, Heat treatment, Scandium.*

1. INTRODUCTION

Aluminum is the most abundant metal available in the earth's crust, steel was the most used metal in 19th century but Aluminium has become a strong competitor for steel in engineering applications. The most attractive properties of aluminum and its alloys which make them suitable for a wide variety of applications are their light weight, appearance, frabricability, strength, and corrosion resistance. Among aluminium alloys AA7075 alloy has many attractive properties compared to other alloy it is economical and versatile to use this is the reason it is very widely used in the aerospace, automobile and other industries.

Norman et al. [1] have studied the solidification of Ultrahigh strength 7xxx series Al-Zn-Mg-Cu aluminium alloy and pointed that it have many shortcomings because they contain a number of alloying elements. The final solid might have some defects like, a variation in composition from the core of the dendrite to the edge. Norman A F et al.[2]. have studied phase diagram of multi component Al-Zn-Mg-Cu-Zr-Sc system and stated that during solidification a few alloying elements and impurities form coarse eutectic networks in the dendrite and along the interdendritic boundary. Because of these issues it is hard to cast and as a result formation of cracks during hot rolling. Glenn A.M et al. [3] have studied the effect of grain refining element on the micro segregation of aluminum magnesium alloy 5182. It is investigated that a united addition of traces of transition elements to Al-Zn-Mg-Cu alloys can improve the metallurgical state of the alloy. Norman A F et al. [4] Examined the effect of Scandium (Sc) on 2000 and 7000 series aluminum alloy castings, for the improvements in fusion welding and pointed that joint addition of Sc and Zirconium (Zr) improves the mechanical strength because of grain refining element.

Yang J L et.al [5] studied site occupation of substitutional elements Cr, Mo, Ti, Mn, Ni and Si at sublattices, effect of the elements on magnetic moment of the unit cell, and tensile properties at room temperature by means of neutron diffractometry. They pointed that Cr,Mo and Ti all occupied the next neighbor of Al atoms by this improvement in mechanical properties of the alloy. Prasad K S et al. [6] studied the effect of Zr to the aluminium alloys and pointed that formation spherical faceted Al_3Zr (β prime) pretcipitates in Al-Li-Cu-Mg-Zr alloys improved the microstructure. Robson J D et al. [7] studied modeling of Al_3Zr dispersoids precipitation in multi component aluminum alloys. They pointed that a small addition of Zr might raise the temperature causing recrystallization, enhance the tensile strength, and decrease the adverse influence of impurity contained in the alloys. Suh D W et.al [8] has studied microstructural evolution of Al-Zn-Mg-Cu-Sc alloy during hot extrusion and heat treatments. They stated that a small Sc addition may help to make α-Al nucleate and this mechanism leads to an enhance in mechanical properties. Furukawa M et al. [9] has studied the effect of Mg alloy and found that precipitation is amplified as Sc and Zn are added together. Iwamura S and Miura Y [10] has studied the loss in coherency and coarsening behavior of Al_3Sc precipitates It is noticeable that the addition of Sc and Zn plays a significant role in Al-Zn-Mg-Cu based alloys in facilitating the precipitation phase which impedes grain growth.

In principle, the grain refinement mechanism is moderately simple in aluminum alloys. It is known that most of the strong heterogeneous nuclei are disperse in to the melting alloy and most of the nucleation sites become active during solidification to nucleate the solid. Easton M A and St john [11] has studied grain refinement incorporating alloy constitution and potency of heterogeneous nucleate particles. They pointed that Zr may become toxic to the Al-Ti-B master alloy because of its atom mismatch. Murty B S et al.[12] investigated the manufacture of Al-Ti-B master alloys by the reaction of complex halide salts with molten aluminum. They reported that the joint addition of minor amounts of Sc and Zn in Al-Mg based alloys improves the mechanical properties.

Although many investigations on grain refinement for Al-Zn-Mg-Cu based alloys have been reported some of them are ambiguous and even contradictory. The literature states that grain refining element is very effective on mechanical properties of aluminium alloys. The alloying element determines whether cast product grain is coarse or fine in turn it determines the mechanical properties. The mechanical properties of high strength AA7075 aluminium alloy is coarse grain. In AA7xxx series aluminium alloy the mechanical properties are improved by adding grain refining elements. Among several grains refining elements Sc is the most effective grain refining elements for aluminum alloy. Heat treatment aluminium alloys heat treatment mainly employed to increase strength and hardness of the precipitation hardenable wrought and cast alloys. The aluminium alloys are usually strengthened by precipitation hardening treatment.

In this study an attempt is made to improve the mechanical properties of AA 7075 alloy by Sc grain refining element and further mechanical properties improved by precipitation hardening process.

2. EXPERIMENTAL WORK

Al-Zn-Mg-Cu (symbolized as AA 7075) is a typical Al-Zn aluminium alloy and its chemical compositions are listed in Table 1. Alloying with Sc elements is adopted in order to improve mechanical properties of Al-Zn-Mg-Cu alloy. The chemical composition of the Al-Zn-Mg-Cu alloy have been analyzed by the method of spectro

Table 1: Nominal and Spectromax Analyzed Chemical Composition of AA7075

Elements present	Nominal composition (Wt%)	Composition (Wt%) as per the spectro spark emission
Aluminium,Al	87.1-91.4 %	90.60%
Zinc,Zn	5.10-6.10%	5.28%
Magnesium ,Mg	2.10-2.90%	2.15%
Manganese ,Mn	≤ 0.300%	0.04%
Chromium, Cr	0.180-0.280%	0.23%
Copper ,Cu	1.20-2.00%	1.31%
Iron ,Fe	≤ 0.500%	0.21%
Other each	≤ 0.0500%	< 00.004 %
Other total	≤ 0.150%	< 00.009 %
Silicon ,Si	≤ 0.400%	0.06%
Titanium,Ti	≤ 0.200%	0.05%

Table 2: Chemical compositions of investigated (EDS) alloys (Weight fraction, %)

Type of Alloy	Zn	Mg	Cu	Si	Sc	Al
AA 7075	6.66	2.82	1.86	0.44	---	Balance
Al- 0.02%Sc (N1)	6.51	2.33	1.73	0.29	**0.02**	Balance
Al-0.07%Sc. (N2)	6.27	2.13	1.61	0.42	**0.07**	Balance
Al-0.23%Sc. (N3)	6.35	2.29	1.09	0.68	**0.23**	Balance

Fig 1. Sand Casting Process

spark emission (ASTM-E1251-07) using a Spark analyzer spectromax. The nominal compositions [4] and composition of Aluminum alloy AA7075 taken up for present work shown in Table 1 and Table 2.

The alloys were melted in a graphite crucible with lid covering to prevent zinc and magnesium from oxidization. Sc was added to the melt using master alloys of Al-2Sc, respectively. The melting temperature was kept as 750°C and the melt was cast into specimens in a sand mould as shown in Fig.1.

The scientist M. Temmar et al. [113] states that, the precipitates in the aluminium alloy can be formed either natural ageing or artificial ageing (T6 tempering) and artificial ageing T6 temper state can be obtained either by aging at 120^{0}C for 24 h or 140^{0}C for 10 hr. In the present investigation aging temperature 140^{0}C and soaking period of 10 hr is selected for aging treatment of cast products. Tensile test is conducted on 60 Ton Universal testing machine. FIE-Bluestar, UTES−60) at room temperature as per the ASTM standards. Three specimens were tested and their average value was calculated as the result. The tensile specimen is loaded at the rate of 1.3kN/min as per the ASTM standards. The cast specimen fails and stress Vs strain diagram is recorded. Yield strength is measured by 0.2% offset method as per the ASTM standards.

For metallography investigation, the sample preparation and polishing are done as per the ASTM E 3-11standard [8] and metallography image obtained by using an Up-right reflected and transmitted metallurgical microscopy system; Make: VT Vacuum Technologies Pvt. Ltd; Model No. EQ-MSXJM213H-3M: incorporated with image analyzing software. The tensile fracture surfaces were observed by using scanning electron microscope (SEM). The tensile test results correlated with optical metallography, and SEM fractography.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Microstructure

The Fig. 2 shows the microstructure, captured using an optical microscope, and of the as cast alloys investigated, where dendrite structures are obviously coarse in the Al-Zn-Mg-Cu alloy. There are a large number of the second phase particles depositing within grains or at the grain boundaries (shown in Fig. 2(a)). When 0.02% and 0.07% Sc is added in the alloys the second phases within the grains disappear while the dendrite structure remains coarse (Fig. 2(b) and Fig. 2(c)). Addition of 0.23% Sc in the alloys allows the formation of equiaxed fine structure (Fig. 2(d)). There is an appreciable change in the microstructure is noticed in the T6 tempering and this is clearly evident from the Fig.5.2 (e). On the other hand, the simple aging treatment applied to the cast products caused perceptible changes in the creation of precipitates and their distribution. This is the reason for improvement in the mechanical properties, which is better than that of the AA7075 (Fig. 2(a)). Several theories have been proposed to explain the mechanism of effective grain refinement achieved by the addition of Sc element [14,15].

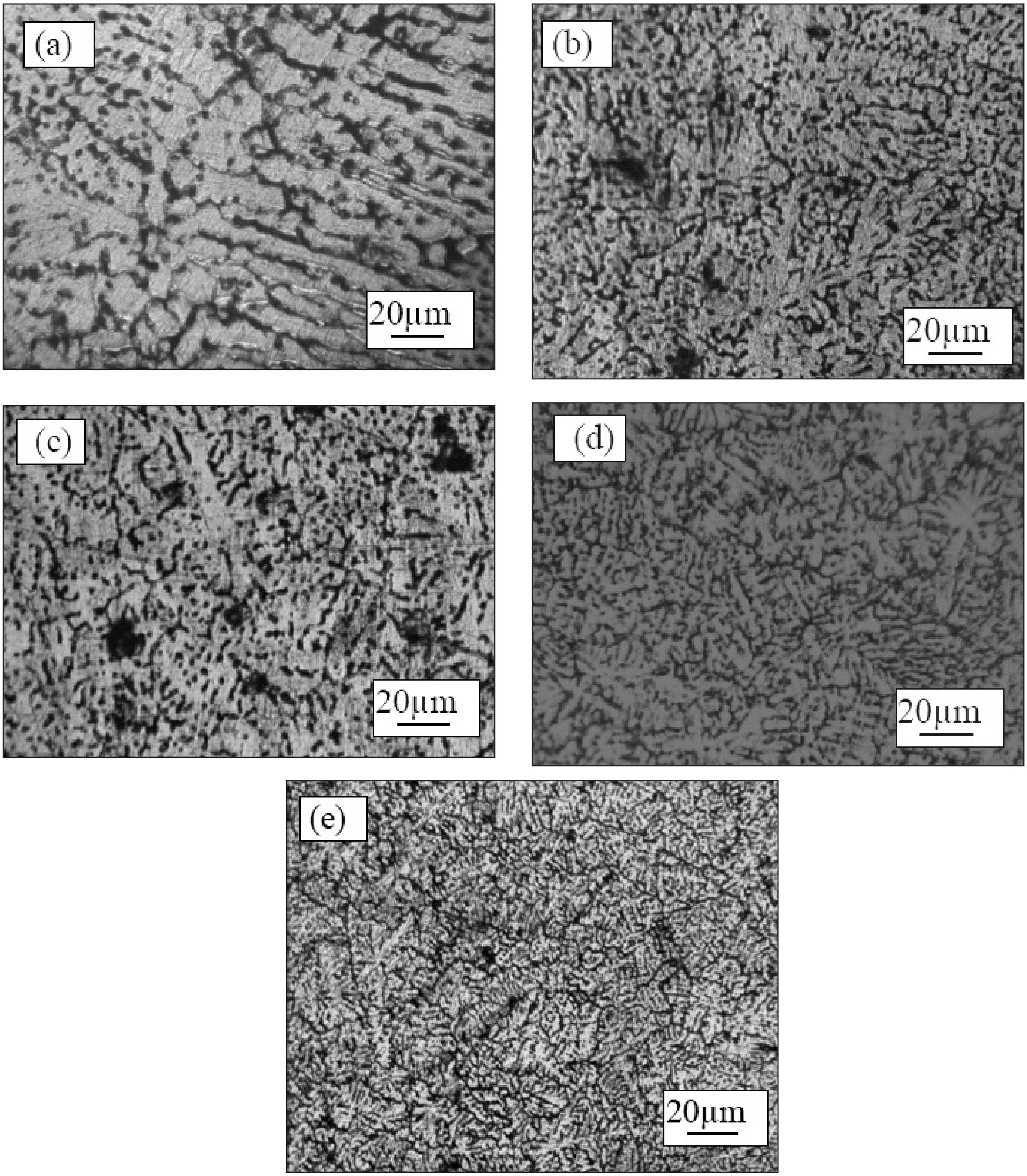

Fig 2. Optical Microstructures of as-cast Alloys: (a) AA7075; (b) AA7075-0.02Sc; (c) AA7075-0.07Sc; (d) AA7075-0.23Sc; (e) AA7075-0.23Sc (After T6 tempering)

Theoretically, the refinement mechanism of aluminum scandium melts changes with variation in the content of Sc. When the Sc concentration is lower, the Sc mainly interacts with atom clusters, forms steady atom clusters, and then grow to finally become nuclei. The role of Sc in helping to nucleate the aluminum alloy can be explained by the duplex nucleation model. According to the binary Al-Sc equilibrium phase diagram, at the Al-rich end there is a eutectic reaction between α-Al and Al_3Sc phase; and the eutectic composition is at the low level of at 0.23% Sc [14-16]. The Al_3Sc phase is a stable heterogeneous particle and can intensively refine aluminum grains when the concentration of Sc in the melt exceeds the critical limit. The effect of Sc is amplified by the simultaneous addition of

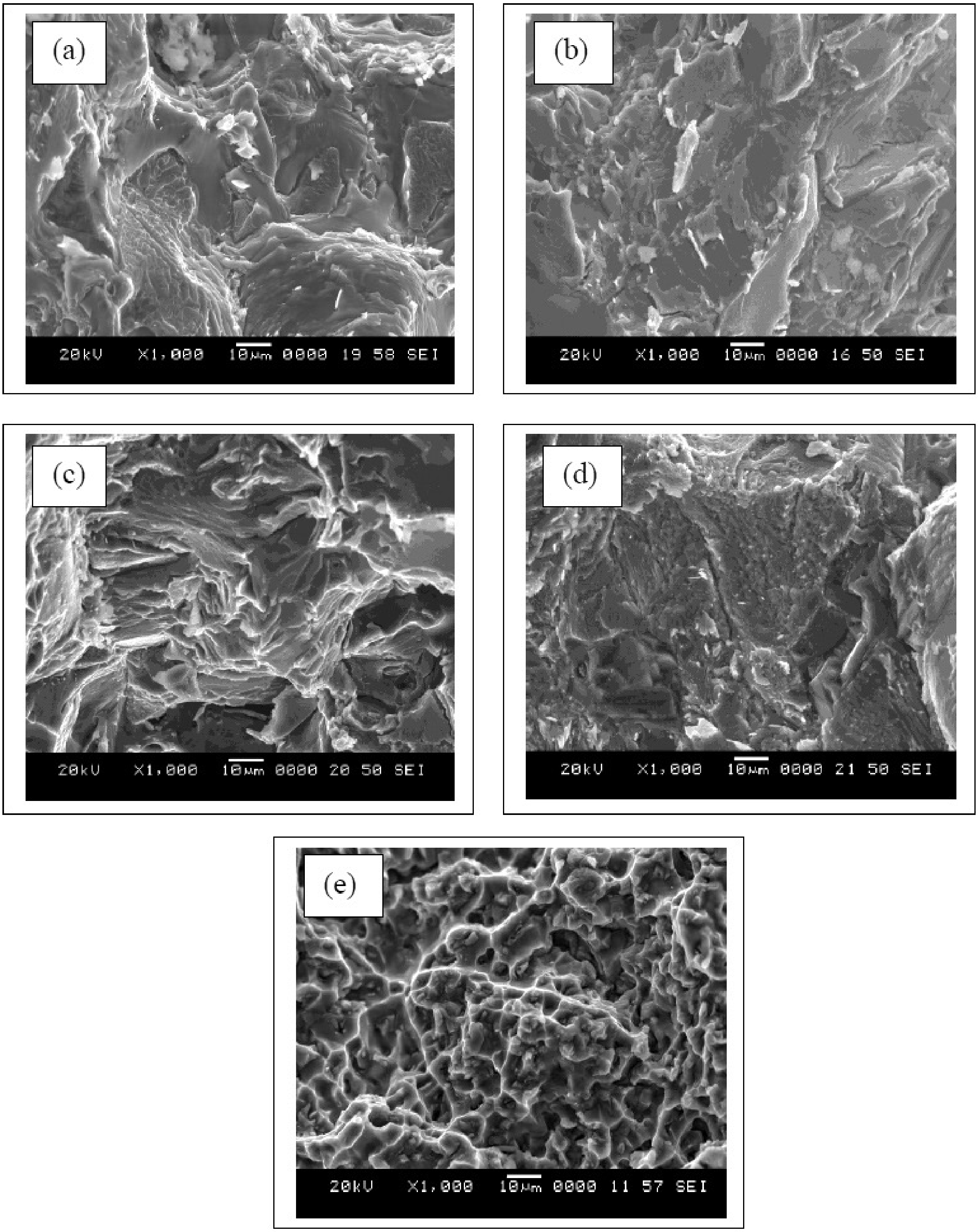

Fig 3. Fractural Micrographs of Al Alloys: (a) AA7075; (b) AA7075-0.02Sc; (c) AA7075-0.07Sc; (d) AA7075-0.23Sc ; (e) AA7075-0.23Sc (After T6 Tempering)

Sc by concentration fluctuation and microstructure wave in the melt due to interaction of Sc and Al.

Once Sc is added to the alloys containing small amounts of Sc, a new Al-Sc crystallite cell can be generated in the melt. The nearest Al-Sc bond has the highest covalent bond energy in AlZnMgCu-Sc alloy, and has a great influence on the combined

Table 3: Tensile Testing Results (Average of three tests)

Base material / Sc added alloy	YS (MPa)	UTS (MPa)	(EL %)
AA 7075	250.8	373.2	8.8
Al- 0.02%Sc (N1)	292.4	402.6	8.6
Al-0.07%Sc. (N2)	313.8	445.4	6.2
Al-0.23%Sc. (N3)	324.3	468.8	5.8
Al-0.23%Sc. (N3) (After T6 tempering)	335.49	485.8	6.2

action of Sc and Al.

3.2 Tensile Properties

Table 3 shows the mechanical properties of the cast alloys at room temperature. The ultimate strength and yield strength of the alloys increase and the elongation decreased with addition of 0.02% Sc to 0.23% to AA7075 alloy. After that, the ultimate strength and yield strength of the experimental alloys continue to increase but the elongation to decrease. After the addition of Sc, the ultimate strength and yield strength of the AA7075 alloy are found to increase by about 29.4 MPa and 49.6 MPa respectively with the addition of 0.02% Sc. After 0.07% Sc addition is found to increase the yield strength very apparently, and the maximum increment of yield strength is up to 63.0 MPa. It should be noted that the addition of 0.02% Sc there is no much decrease the elongation of the alloy, while the yield strength is increased by about 41.6 MPa.

After 0.07% Sc addition, the ultimate strength and yield strength of the AA7075-0.07Sc alloy increase to 313.8 MPa and 445.4 MPa, respectively, higher than that of AA7075 alloy by about 63 and 72.2 MPa, respectively. In the AA7075-0.23Sc alloy, the ratio of yield strength to ultimate strength is 0.69, which suggests that Sc element can be used to develop the new types of wrought Al-Zn alloys with high yield strength.

The improvement of the strength of the AA7075 alloy by the addition of Sc may be attributed to three factors. Firstly, Sc addition results in the grain refinement of the AA7075 alloy. With addition of Sc, the microstructure of the as-cast alloys is refined and the growth of recrystallized grains is suppressed during casting. After Sc addition, the grain refinement caused by the addition of Sc is more obvious and the grain size is decreased by about 60% with addition of Sc to the AA7075 alloy. According to the Hall-Patch formula [14] and related work[12, 13], the grain refinement is very helpful to improve the yield strength of wrought Al Zn alloys. Another factor is the high solid solubility and low diffusion of Sc in Al alloys [14,15]. The decrease of elongation in the AA7075 Sc alloys can be attributed to the formation of some coarse compounds containing Sc.

The fracture types of the Al- Zn alloys mainly include cleavage fracture, quasi cleavage fracture and intergranular fracture [11-13]. Due to the limited slip systems in Al- Zn alloys, the appearance of dimples needs to activate multi slipping. Fig.3 shows the fractural micrographs of the Al- Zn and AlZnSc alloys. The fracture surface of the AA7075 alloy is composed of tearing ridges, quasi cleavage steps and a small amount of dimples. The fracture behavior is between ductile fracture and brittle fracture. In the Sc containing AA7075 alloys, the cleavage planes and steps are observed clearly, which suggests that the brittle fracture feature is more obvious in the AA7075 Sc alloys. The above results indicate that the ductility decreases with the addition of Sc, which are concordant with the results of tensile testing.

The Fig.3 (e) shows the fractographs of T6 heat treated tensile specimens. The displayed fractographs regularly consist of dimples, which are indication that the tensile specimens failed in ductile manner under the action of tensile loading. There is a significant distinction exists in the size of the dimples with respect to the AA7075 alloy Fig.3(a).

5.CONCLUSION

The following conclusions are drawn from the experimental results and relevant references of the literature survey conducted during the present work.

It has been shown that extremely diverse solidification behavior can occur in Al-Zn-Mg-Cu-Sc alloys. The refinement mechanism varies with the elements which are added to the base alloys. The addition of 0.02 % Sc has little effect in grain refinement because Sc is mainly dissolved into the matrix and primary Al_3Sc particles are hardly precipitated. The 0.23% addition of Sc gives more equiaxed grains than other additives, giving cast grain sizes as fine as 10 – 15 µm.

The tensile strength and yield strength in the AA7075 alloys increase with the increase of Sc content, but the elongation decreases. After 0.07%Sc addition results in an obvious improvement on the yield strength of the alloy. 0.23% Sc addition increases the yield strength of AA7075 alloys by about 73.5 MPa and the elongation decreased by 34%. The yield strength of the AA7075 -0.23% Sc alloy increases up to 324.3 MPa, which is 0.69 time that of the Ultimate tensile strength of the AA7075 -0.23% Sc alloy.

By simple T6 tempering treatment to the AlZnMgSc alloy, the ductility is increased due to the formation of precipitates and their distribution.

REFERENCES

1. Norman, AF; Prangnell, PB; Mcewen, RS: The solidifi cation behavior of dilute aluminum-scandium alloys, 'Acta Materialia', 1998, 46(16): 5715-5732.
2. Rokhlin, LL; Dobatkina, TV; Bochvar, NR; Lysova, EV: Investigation of phase equilibrium in alloys of the Al-Zn-Mg-CuZr-Sc system, 'Journal of Alloys and Compounds', 2004, 367:10-16.
3. Glenn, AM; Russo, SP; Gorman, JD; Paterson, PJK: The effect of grain refining on the micro-segregation of aluminum magnesium alloy 5182, 'Micron', 2001, 32: 841-850.
4. Norman, AF; Hyde, K; Costello, F; Thompson, H; Birley, S; Prangnell, PB: Examination of the effect of Sc on 2000 and 7000 series aluminum alloy castings: for improvements in fusion welding, 'Materials Science and Engineering A', 2003, 354: 188-198.
5. Yang, JL: Neutron diffraction study on site occupation of substitutional elements at sub lattices in Fe3Al inter metallics, 'Materials Science and Engineering A', 1998, 258: 69-74.
6. Prasad, KS; Gokhale, AA; Mukhopadhyay, AK; Banerjee, D; Goel, DB: On the formation of faceted Al3Zr (β prime) precipitates in Al-Li-Cu-Mg-Zr alloys, 'Acta Materialia', 1999,47(8): 2581-2592.
7. Robson, JD; Prangnell, PB: Modeling Al3Zr dispersoids precipitation in multi-component aluminum alloys, 'Materials and Engineering A', 2002, 352: 240-250.
8. Suh, DW; Lee, SY; Lee, KW; Lim, SK; Oh KW: Microstructural evolution of Al-Zn-Mg-Cu-Sc alloy during hot extrusion and heat treatments, 'Journal of Materials Processing Technology', 2004, 155-156: 1330-1336.
9. Furukawa, M; Utsunomiya, A; Matsubara, K; Horita, Z: Influence of magnesium on grain refinement and ductility in a dilute Al-Sc alloy, 'Acta Materialia', 2001, 49: 3829-3838.
10. Iwamura, S; Miura, Y: Loss in coherency and coarsening behavior of Al3Sc precipitates, 'Acta Materialia', 2004, 52: 591-600.
11. Easton, MA; Stjohn, DH: A model of grain refinement incorporating alloy constitution and potency of heterogeneous nucleate particles, 'Acta Materialia', 2001, 49: 1867-1878.
12. Murty, BS, Kori, SA, Venkateswarlu, K; Bhat, RR; Chakraborty, M: Manufacture of Al-Ti-B master alloys by the reaction of complex halide salts with molten aluminum, 'Journal of Materials Processing Technology', 1999, 89-90: 152-158.
13. Temmar, M; Hadji, M; Sahraoui, T: Effect of post-weld aging treatment on mechanical properties of Tungsten Inert Gas welded low thickness 7075 aluminium alloy joints, 'Materials and Design', 32, 2011, 3532–3536.
14. Villars, P; Calvert, LD: Pearson´s Handbook of Crystallographic Data for Inter-metallic Phase. Metals Park, Oh: American Society for Metals, USA, 1985.
15. Greer, AL; Bunn, AM; Tronche, A; Evans, PV; Bristow, DJ: Modeling of inoculation of metallic melts: application to grain refi nement of aluminum by Al-Ti-B, 'Acta Materialia', 2000, 48: 2823-2835 ◘

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