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Study on Modified heat treatment of Direct Chill Cast 7075 Aluminum Alloy.

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***Abstract*— The effect of heat treatment on microstructure, hardness and tensile properties of the direct chill cast Al-Zn-Mg-Cu (7075) alloy has been evaluated in this research work. To achieve the properties of cast 7075 alloy, comparable to that of wrought, it was subjected to conventional T6 heat treatment as well as modified T6 heat treatment cycle. Higher quenching rate and 2 stage ageing cycle of modified T6 heat treatment cycle, improves the mechanical properties of as cast alloy like Hardness (90 BHN to 140 BHN) and Tensile strength (221 Mpa to 464 MPa).**

***Keywords*— Cast 7075 alloy, Conventional T6 heat treatment, Double step ageing, Modified T6 heat treatment, Microstructure, Tensile strength**

I. Introduction

The Al-Zn-Mg-Cu (7XXXseries) alloys have been widely used in aerospace industry due to their desirable specific mechanical properties.[1-4] 7XXX alloys are generally used in wrought conditions and they can be artificially aged to achieve high strength and hardness which is mainly attributed to the formation of η' ($MgZn_2$) or T' ($Mg_3Zn_3Al_2$) phases which precipitates during ageing treatment depending on the ratio of Zn:Mg present (η' for high ratio and T' for low ratio) in the system.[5-9] As cast 7XXX alloys has a cored dendritic microstructure with an inter-dendritic distribution of second phase particles or eutectics. The inter-granular or inter-dendritic networks of these second phase particles results in inferior mechanical properties of as cast alloys as compared to that of wrought alloys. Efforts are made to optimize the properties of as cast Al-Zn-Mg-Cu alloys [10-12]. The effect of addition of Sc, Zr etc is evaluated on cast ingots.[11] Jie Dong et al [12] worked on low frequency electromagnetic casting techniques to reduce the average grain size to improve the mechanical properties. All these techniques however focuses on rapid solidification techniques to reduce the grain size and to minimize the macro-segregation of second phases which are not only expensive but also limits their application in manufacturing products from these alloys.

Cast alloys as well as wrought alloys are both usually subjected to T6 thermal treatment to attain peak strength. Conventional T6 treatment cycle consists of solutionizing at 475 ^{0}C for 3 hours to get supersaturated solid solution followed by quenching in water and then artificially aging for 24 hours at 120 ^{0}C. One of the most important parameter in this treatment is the rate of quenching which must be sufficiently high enough to retard heterogeneous segregation of second phases at the high angle grain boundaries and to maintain a certain number of vacant lattice sites required for precipitates to form during aging which contributes to the strength of the alloy [13]. Another important factor to be considered is the time of exposure at the room temperature before the start of precipitation treatment which is detrimental as GP zones formed from supersaturated solid solution at this temperature are not stable during aging treatment and GP zone reversion takes place at higher temperatures. In order to overcome this, two stage aging cycle is performed which consists of pre-aging the alloy at lower temperature to form GP zones which are stable when temperature is raised to final aging temperature [13]. In this study, idea is to cast 7075 (a very popular alloy of 7XXX family used widely in aerospace industry) using simple gravity die casting process and then subject it to the modified T6 thermal treatment using two step aging cycles. An attempt has been made here to optimize the microstructure of as cast alloy using modified T6 thermal treatment to attain its mechanical properties comparable to that of wrought alloy system.

II. Experimental Procedure

The 7075-T6 wrought alloy is first melted in a resistance heating furnace at the temperature of 635 ^{0}C. Superheating at temperature 40 ^{0}C -50 ^{0}C above the melting range is done to ensure complete melting of the charge. After degassing and slag removal operations on the melt, it is poured into metallic dies to get cylindrical specimens which were then subjected to conventional T6 as well as modified T6 heat treatment cycles as shown below.

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A. Conventional T6 Heat treatment cycle:

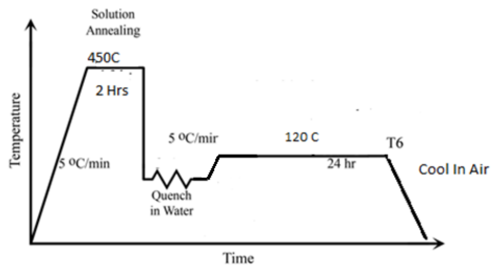

Figure 1: Schematic of conventional heat treatment cycle (single step ageing).

Conventional T6 heat treatment consists of solutionising the alloy at 450^{0}C and hold for 2 hours in order to get homogeneous phase throughout the sample. This is carried out in Platinum wound resistance heating furnace. Then quenching was carried out in warm water followed by ageing treatment was given in which sample was hold for 24 hours at 120^{0}C.Sample was then air cooled.

B. Modified T6 Heat treatment cycle:

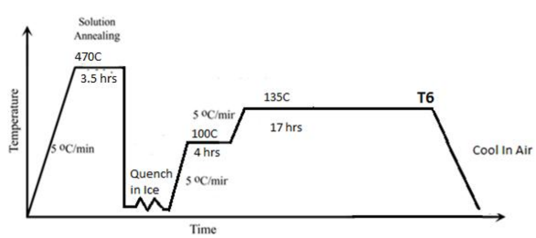

Figure 2: Schematic of modified heat treatment cycle (dual step ageing).

Modified heat treatment consists of solutionizing treatment at 470^{0}C and hold for 3.5 hours in order to get homogeneous phase throughout the sample. This is carried out in Pt. wound resistance furnace. The sample was then quenched in Ice cold water. After that two step ageing treatment was given in which sample was:

- Pre-ageing at 100^{0}C and hold it for 4 hours.
- Final ageing at 135^{0}C and hold for 17 hours.
- Sample was then air cooled.

Material characterization of wrought, cast, conventional and modified T6 heat treated alloys was done by chemical analysis, microstructure analysis, hardness testing and tensile testing.

Microstructure analysis was performed on Jeol 5610LV SEM (Scanning Electron Microscopy). Hardness testing was performed on BHN hardness tester using 31.625 kg of load having a ball diameter of 25mm.

An Average of six values was taken. Tensile tests were performed using a Monsanto 20 tensile testing machine while maintaining a constant crosshead speed of 0.5 mm per minute. The ultimate tensile strength and % elongation was determined in each case and an average of 3 values was taken into consideration. EDS (Energy Dispersive Spectroscopy) analysis was done to evaluate the chemical composition of the various phases formed.

III. RESULT & DISCUSSION

A. Chemical Composition:

The chemical composition of the 7075 alloy used for this study as evaluated by means of EDS (Energy Dispersive Spectroscopy) is listed in TABLE I.

Table I
Chemical Composition Of Wrought 7075 Alloy.

Wrought 7075 alloy	Zn wt%	Mg wt%	Cu wt%	Ti wt%	Cr wt%	Rest Al wt%
	5.74	2.45	1.70	0.10	0.34	89.67

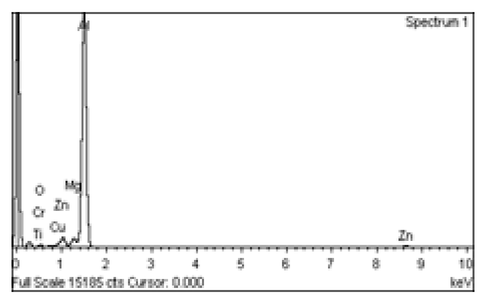

Figure 3: X-ray spectrum of wrought alloy.

The wrought 7075 alloy which has total alloy contains around 9.89wt%. After melting and casting chemical composition indicates loss in the % of Zn and Mg which is due to the lower melting point of Zn and Mg. Zn % decrease from 5.74 to 5.41 and Mg decreases from 2.45wt% to 1.99 wt.% as indicated in TABLE II.

TABLE II
Chemical Composition Of As Cast 7075 Alloy.

Cast 7075 alloy	Zn wt%	Mg wt%	Cu wt%	Ti wt%	Cr wt%	Rest Al wt%
	5.41	1.99	1.70	0.10	0.22	90.58

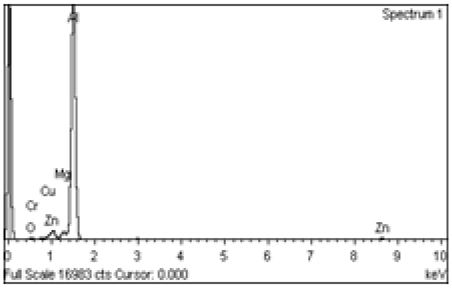

Figure 4: X-ray spectrum of as cast 7075 alloy.

Decrease in Zn & Mg content further decreases the strength of the alloy attainable by heat treatment.

B. Microstructure Analysis:

Following fig no 5 shows the BSE (Back Scattered Electron) micrographs of wrought, as cast, conventional T6 heat treated (single step ageing) and modified T6 heat treated (Double Step Ageing) samples. The BSE provides a clear contrast between Al- matrix phase and second phases enriched in Zn, Mg and Cu as evident from their X-ray spectrum shown in fig-6.

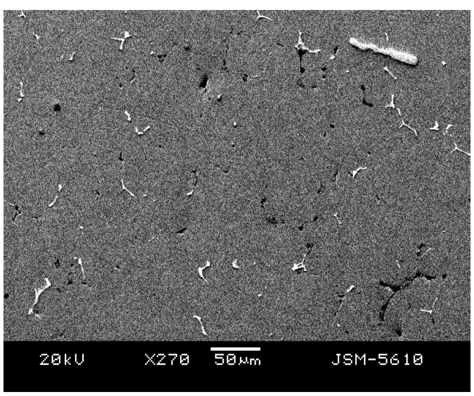

Figure 5a: Wrought 7075-T6 alloy.

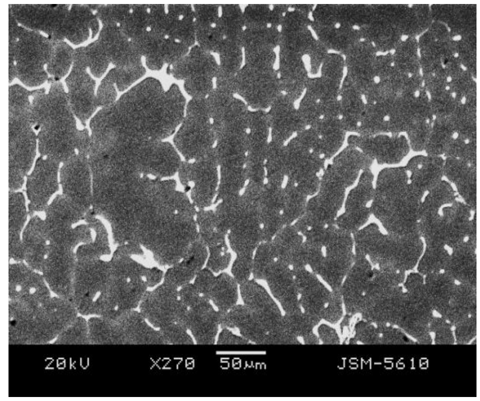

Figure 5b: As Cast 7075 alloy.

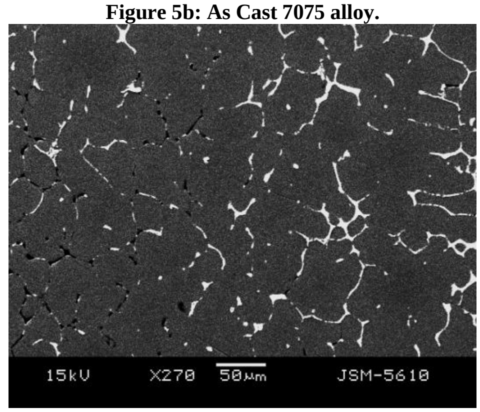

Figure 5c: Conventional T6 Heat treated (Single step ageing)

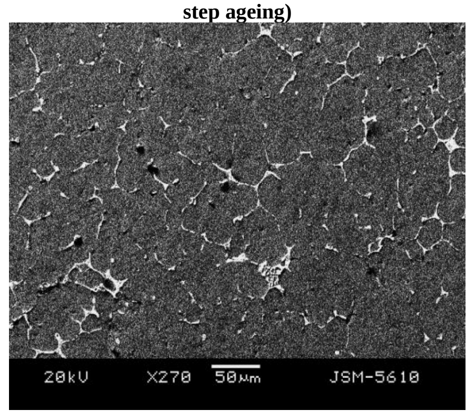

Figure 5d: Modified T6 Heat treated (Double step ageing)

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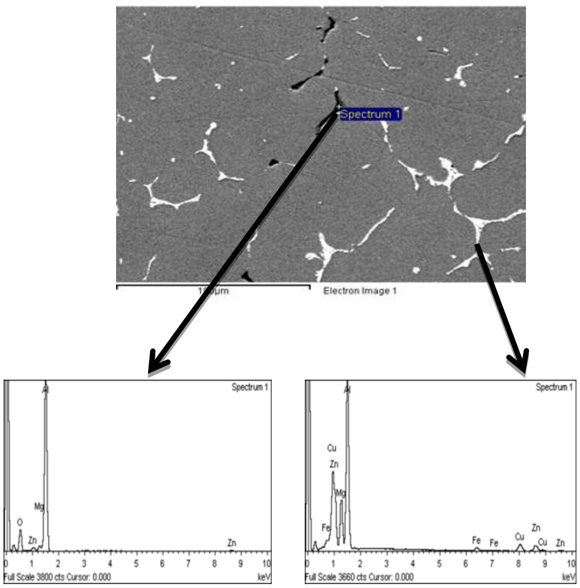

Figure 6: X-ray spectrum of the phases present.

The as cast sample of 7075 alloy has the dendritic microstructure (figure 5b) of alpha aluminum along with inter-dendritic segregation of second phases of Zn, Mg & Cu. Upon heat treating, this dendritic structure is completely broken and replaced by grains (figure 5c) with inter-granular segregation of Zn, Mg, Cu rich phases which occurs due to slow cooling rate in warm water quenching operation, allowing second phase to precipitate along grain boundaries. This is not desirable as amount of solute available to form precipitates during ageing treatment is reduced and hence optimum strength could not be achieved. In a contrast to this, when quenching rate is high, the segregation is noticeably reduced as can be seen from (figure 5d). Furthermore this will enhance the precipitation hardening effect upon ageing. Apart from white phases, some discontinuous black phases were also present in as cast and heat treated samples of 7075 alloy whose EDS analysis indicates the presence of oxides of Al, Mg, Zn. The wrought 7075-T6 alloy has the most desirable microstructure (figure 5a) with negligible segregation of second phase and absence of oxide inclusions.

C. Mechanical Properties:

The following table 3 indicates the measured tensile, %elongation and hardness values of wrought, as cast, conventional as well as modified heat treated 7075 alloys.

Table III
Mechanical Properties Of 7075 Alloy In Different Conditions

Sample Condition	**Ultimate Tensile strength (MPa)**	**Elongation %**	**Hardness (BHN)**
Wrought	555	11	130
As Cast	221	4	90
Conventional Heat–Treated (Quench in Warm Water + single step aging at 120^{0}C for 24 hr)	324	6	130
Modified Heat-Treated (Quench in Ice water + double step aging).	464	6	140

From above table we observed that wrought 7075-T6 alloy shows tensile strength of 555Mpa with % of elongation of 11% and hardness of 130 BHN. Thus it has very good toughness and strength values owing to its well developed or desired micro structure. The presence of heavy segregations in as cast alloy results in the drastic reduction in tensile values from 555Mpa to 221 Mpa and % elongation reduces from 11% to 4%. After standard T6 condition that is warm water quenching and single step ageing improvement in tensile strength from 221 Mpa of cast condition to 324 Mpa observed. % elongation also increases from 4% of cast to 6%. Both, the tensile strength as well as % elongation is not enough to have same performance as that of wrought 7075 alloy. To improve these properties, modified heat treatment was tested with double step ageing treatment as shown discussed in experimental procedure. The double step ageing followed after ice water quenching changes its tensile properties from 221Mpa to 464Mpa and % elongation remains almost same as that of Single step ageing cycle. Hardness values also increases from 130 BHN to 140 BHN. The improvement in tensile strength from 221 to 464Mpa means almost double in values after double step ageing cycle. It is due to reduction in macro segregates of Zn, Mg, Cu enriched phases. The EDS analysis confirms the presence of phases generated after double stage ageing.

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IV. CONCLUSION

- Casting of 7075 alloy requires careful casting practice as there was loss of approximately 5% Zn and 2.0% Mg after casting.
- The rapid quenching of as cast alloy in ice water after solutionising, reduces the segregation of Zn, Mg, Cu.
- The modified heat treatment (Rapid quenching + double step ageing) improves the mechanical properties of as cast alloy and this improvement is significantly higher than that achieved by conventional heat treatment cycle.
- With rapid quenching along with double step ageing, improvement in mechanical properties in the range of 80 % - 85 % of that of wrought alloy can be achieved.

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