Analysis of Strength Variation in Aluminium Alloys Due to Heat Treatment & Welding

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Abstract— Aluminium, in its pure state, is soft and ductile; not very strong. Addition of foreign elements like copper (Cu), magnesium (Mg), and silicon (Si) can easily change the physical and mechanical properties of pure aluminium. This foreign addition of these elements is typically very less (a few % of total solution) [1]. This doping of foreign elements like Si, Mg, Cu plays an important and crucial role in deciding the properties of aluminium alloy and cherish the alloys with desired properties. After giving desired properties these aluminium alloys become very useful for various products and application. Due to its extremely light-weight and corrosion resistance nature, the aluminium alloy is extensively being used in structural application [2]. The current example is aerospace industry, which is using these alloys to design aircrafts that are light-weight, faster than conventional aircrafts and more importantly fuel efficient. The first use of aluminium alloys in airplanes was in the early 1900's. At that time copper (Cu) was being used to strengthen the alloy. Copper (Cu) gave birth to new development series, now commonly used 2XXX series, of aluminium alloy (Al-Cu-Mg).

Keywords: Aluminium Alloys, Heat Treatment & Welding

I. Introduction

In comparison to pure aluminium, aluminium alloy has solute particle added in it which effects grain structure and microstructure within the grains. Thus, each alloy, mixed with different proportion of solute particles, acts differently to heat treatment and exhibit different working conditions. The properties of 6XXX Al-Mg-Si alloys can be affected by the equilibrium phase of Mg_2Si (β). Additional hardening phase appear with copper addition in 6XXX series aluminium alloy [3]. The appearance of these phases makes the alloys temperature and time sensitive when aging. The 6XXX series alloys are better than 2XXX series alloys in terms of giving better corrosion resistance and slightly higher strength. A major benefit to the 6XXX series alloys is the extrudability due to the addition of silicon.

II. Welding and Heat Treatment

Welding of aluminium alloys has been known to be difficult task and result in a decrease in strength near weld heat affected zones (HAZ). Spray transfer Gas metal arc welding (GMAW) is the most common process for welding aluminium alloy. Spray transfer allows many small drops of filler metal to spray across the arc from the electrode wire to the base metal. This results in a larger weld puddle therefore limiting the possible weld positions to only lap joint and fillet welds. Argon and argon/Helium mixture is most commonly used Shielding gas. During welding of metals, it is especially pay attention that base metal surface must be free from any contamination because any kind of contamination, if not removed, can results in poor weld quality and decreased material strength [4]. The melting point of base metal aluminium is 660℃ and melting point of aluminium oxide is 2000℃. This is very clear that aluminium oxide layer is stronger than base aluminium and it must be properly removed with wire brush.

If welding surface is not prepared before welding, then not melted particles of oxide will enter into the weld pool and will create discontinuities in the material microstructure. Weld cracking may occur due to the fact that aluminium dissipate heat quickly. Preheating can be used to prevent cracking and cold welds.

To prevent the migration of constituents from solution we can use quenching. Aging process is followed after quenching, aging is done for a few days at room temperature to obtain the alloy in natural temper [3]. After natural aging is completed, then artificial aging is done to obtain different temper conditions. This process is referred as precipitation heat treatment. Material temper is time sensitive and temperature sensitive [4]. Mg_2Si (Magnesium silicide i.e., second phase particles) are precipitated from the material matrix during the process of precipitation heat treating. Stress of material is relieved and strength of the material is enhanced after this process.

III. Test Specimen Preparation

Keeping in mind BIS (Bureau of Indian Standards) standards, tensile test specimens was prepared. For convenience in testing each aluminum alloy test sample was in rectangular sections [1]. Aluminium alloy grade AA6061, AA6063 and AA6005A were taken and Three variety of thickness were cut 1/4" (6.35 mm), 1/8" (3.17 mm) and 3/8" (9.53 mm). Length of each sample taken was 150 mm. After cutting the samples, some samples were randomly selected for to obtain samples with HAZ (Heat Affected Zone) [6]. Randomly selected samples were welded and after that that weld bead is removed leaving parent metal only (with HAZ). The machine used, for removing the weld from the sample, is vertical hand mill (see fig. 1). Final tensile test shape is obtained, after removing weld, by CNC router (for accuracy) [5]. A desired quantity of welded samples and desired quantity of un-welded samples were chosen for heat treatment before testing.

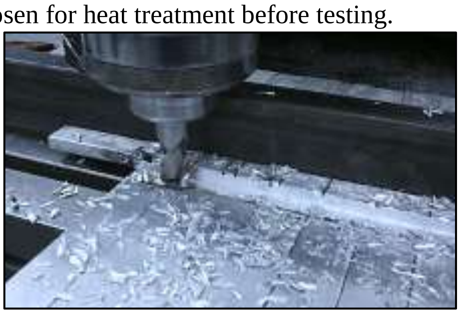

Fig. 1: Weld removal by vertical milling machine

Fig. 2: Final Testing Shape

AA6061, 1/4" (6.35 mm)		
Strain (%)	Stress (MPa)	
	AW	PWHT
0.2	109.1 (Y)	261.3 (Y)
2	151.3	280.9
4	177.6	285.4
6	187.6	289.7 (U)
8	210.9	245
10	211.7 (U)	NA
12	185.4	NA
14	NA	NA

Table 1: Stress-Strain relationship of AW & PWHT (AA6061, 1/4", 6.35 mm)

Yield and Ultimate tensile strength (UTS) of AA6061, 1/4" (6.35 mm)

Yield Strength in AW condition = 109.1 MPa

Yield Strength in PWHT condition = 261.3 MPa

$$\text{Percentage increase in yield strength} = \frac{increase\ amount}{original\ value} \times 100 = \frac{261.3-109.1}{109.1} \times 100 = 139.5\ \%$$

Ultimate tensile strength (UTS) in AW condition = 211.7 MPa

Ultimate tensile strength (UTS) in PWHT condition = 289.7 MPa

Percentage increase in Ultimate tensile strength (UTS)=

$$\frac{increse\ amount}{original\ value} \times 100 = \frac{289.7-211.7}{211.7} \times 100 = 36.84\ \%$$

Yield Strength in AR condition = 132.2 MPa

Yield Strength in AW condition = 109.1 MPa

$$\text{Percentage Decrease in yield strength} = \frac{decrease\ amount}{original\ value} \times 100 = \frac{109.1-132.2}{132.2} \times 100 = -17.47\ \%$$

Ultimate tensile strength (UTS) in AR condition = 239.7 MPa

Ultimate tensile strength (UTS) in AW condition = 211.7 MPa

Percentage decrease in Ultimate tensile strength (UTS)=

$$\frac{Decrease\ in\ amount}{original\ value} \times 100 = \frac{211.7-239.7}{239.7} \times 100 = -11.68\ \%$$

Due to welding heat and heat affected zone created (HAZ) the strength, both yield and ultimate, decreases in comparison with as- provided AA6063 (9.53 mm).

Yield Strength decreases by 17.47 %

Ultimate tensile strength (UTS) decreases by 11.68 %

AA6005A, 1/4" (6.35 mm)		
Strain (%)	Stress (MPa)	
	AW	PWHT
0.2	72.1 (Y)	151.3 (Y)
2	105.3	178.4
4	131.8	183.4 (U)
6	140.7	177.7
8	145.4 (U)	174.5
10	140.3	NA
12	138.1	NA

Table 2: Stress-Strain relationship of AW & PWHT (AA6005A, 1/4", 6.35 mm)

Yield and Ultimate tensile strength (UTS) of AA6005A, 1/4" (6.35 mm)

Yield Strength in AW condition = 72.1 MPa

Yield Strength in PWHT condition = 151.3 MPa

$$\text{Percentage increase in yield strength} = \frac{increase\ amount}{original\ value} \times 100 = \frac{151.3-72.1}{72.1} \times 100 = 109.8\ \%$$

Ultimate tensile strength (UTS) in AW condition = 145.4 MPa

Ultimate tensile strength (UTS) in PWHT condition = 183.4 MPa

Percentage increase in Ultimate tensile strength (UTS)=

$$\frac{increse\ amount}{original\ value} \times 100 = \frac{183.4-145.4}{145.4} \times 100 = 26.13\ \%$$

Yield Strength in AR condition = 87.2 MPa

Yield Strength in AW condition = 72.1 MPa

$$\text{Percentage Decrease in yield strength} = \frac{decrease\ amount}{original\ value} \times 100 = \frac{72.1-87.2}{87.2} \times 100 = -17.31\ \%$$

Ultimate tensile strength (UTS) in AR condition = 169.7 MPa

Ultimate tensile strength (UTS) in AW condition = 145.4 MPa

Percentage decrease in Ultimate tensile strength (UTS)=

$$\frac{Decrease\ in\ amount}{original\ value} \times 100 = \frac{145.4-169.7}{169.7} \times 100 = -14.31\ \%$$

Due to welding heat and heat affected zone created (HAZ) the strength, both yield and ultimate, decreases in comparison with as- provided AA6063 (9.53 mm).

Yield Strength decreases by 17.31 %

Ultimate tensile strength (UTS) decreases by 14.31 %

IV. Conclusion

We can clearly see a percentage increase in ultimate tensile strength and yield strength.

Due to welding heat and heat affected zone created (HAZ) the strength, both yield and ultimate, decreases in comparison with as- provided AA6063 (9.53 mm).

- Yield Strength decreases by 17.47 %
- Ultimate tensile strength (UTS)decreases by 11.68 %

Due to welding heat and heat affected zone created (HAZ) the strength, both yield and ultimate, decreases in comparison with as- provided AA6063 (9.53 mm).

- Yield Strength decreases by 17.31 %
- Ultimate tensile strength (UTS) decreases by 14.31 %

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