A Review on Influence of Various Technological Processes on Mechanical Properties of Aluminum Alloys

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Abstract: Aluminum alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. Aluminum alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Selecting the right alloy for a given application entails considerations of its tensile strength, yield strength, fatigue strength, ductility, microhardness, weldability and corrosion resistance. The processes such as shot peening, age hardening, hydrostatic extrusion, friction stir welding, tungsten inert gas welding, quenching, sand casting, gas metal arc welding effect the various above mentioned mechanical properties of alloys. This paper gives a brief review on various processes used for improving the mechanical properties of Aluminium alloys.

Keywords: Aluminum, microhardness, shot peening.

1. Introduction

Aluminum is the world’s most abundant metal and is the third most common element, comprising 8% of the earth’s crust. The versatility of aluminum makes it the most widely used metal after steel. Pure aluminum is soft, ductile, corrosion resistant and has a high electrical conductivity. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications. Aluminum is one of the lightest engineering metals, having a strength to weight ratio superior to steel. It has a density around one third that of steel and is used advantageously in applications where high strength and low weight are required. When the surface of Aluminum metal is exposed to air, a protective oxide coating forms almost instantaneously. This oxide layer is corrosion resistant and can be further enhanced with surface treatments such as anodising. The best alternatives to copper are Aluminum alloys in the 1000 or 6000 series. These can be used for all electrical conduction applications including domestic wiring. The effect of fatigue strength improvement achieved by imparting of hardness and repairing of casting defects by peening impact. Age hardening, also known as precipitation hardening is a low temperature heat treating
process to increase the strength and mechanical properties of many Aluminum alloys. The hydrostatic extrusion process results in a profound refinement of both the grain size and the inclusions in 6082 aluminum alloy. Friction stir welding process is primarily used on Aluminum; most often extruded Aluminum. This process is used to produce long lengths of welds in Aluminum without the need to melt the base material. This eliminates the possibility of solidification cracking and provides important metallurgical benefits when compared to other, more conventional welding methods. Research shows that in case of tungsten inert gas welding, pulse welding current refines the microstructure and improves tensile strength and hardness. Quenching is the rapid cooling of a workpiece in water, oil or air to obtain certain material properties. Quench hardening is a mechanical process in which steel and aluminum alloys are strengthened and hardened. This is done by heating the material to a certain temperature, depending on the material. This produces a harder material by either surface hardening or through-hardening varying on the rate at which the material is cooled. The material is then often tempered to reduce the brittleness that may increase from the quench hardening process. Items that may be quenched include gears, shafts, and wear blocks. Sand casting interplays between various parameters and when optimum conditions are achieved, there will be profound improvement in the microstructure of the alloys as per the study. Gas Metal Arc Welding is known for providing equally high quality joints as that provided by Tungsten Inert Gas Welding in aluminum alloys.

2. Review

Number of papers are presented on the influential processes on mechanical properties of Aluminum alloys. The following reviews give a brief insight of the process like age hardening, shot peening, hydrostatic extrusion, friction stir welding, tungsten inert gas welding, quenching, sand casting, gas metal arc welding having their influences on different alloy properties.

1) Wagner (1999), Guechichi H et al. (2006) deal with shot-peening process that is successfully applied in the aircraft production for enhancing various material properties, i.e. for increasing fatigue strength of the material and strengthening crystal layers of the material, for prevention of corrosion and emerging micro-fractures and for removal of friction and forging effects. Also the process is used for decontamination of material surface as well as for the creation of smooth surfaces (low roughness) for painting purposes.

2) Markovina R et al. (2008) say the number of influential parameters on the shot-peening process is large: type, size and shape of the shots, time of peening, stream velocity, air pressure on the peened element, distance from nozzle to material surface (peening distance), nozzle angle, peening intensity and surface coverage percentage. Experience showed that some of the parameters may be taken as constant while others must be evaluated through experiments and numerical simulations.

3) Dario Ban et al. (2008) showed that the shot-peening is low cost, reliable and easily repeatable procedure that can be used not only for increasing material properties, like fatigue strength and corrosion resistance, but also for shaping structural elements. It is pointed here that defining the proper process parameters is of vital importance for the application of peen-forming.

4) Rafiq A Siddiqui et al. (1999) presented that the 6063 Aluminum alloy were given various heat treatments at under-aged, peak-aged and over-aged temperatures. The effect of precipitation on the tensile strength, yield strength, hardness, ductility and number of cycles required to fail the
alloy at constant stress was investigated. The variation in time and temperature have improved the mechanical properties of the Al-alloy, whereas the ductility has decreased. The experimental work has revealed that time and temperature plays a very important role in the precipitation hardening process of the Al-alloy. A complex sequence of time and temperature dependent changes is responsible in precipitation hardening of 6063 Aluminum alloy. The experimental results have revealed that aging between 8 h and 10 h at 448 K is the most suitable combination of time and temperature imparting maximum tensile strength, yield strength and hardness to the alloy.

5) Okorafor (1991) investigated the corrosion resistance property of 6063 alloy in under-aged, peak-aged and over-aged conditions. The results show that weight loss and rate of weight loss were both function of exposure time and heat treatment temperature.

6) P Wiecinski et al.(2009) aimed to optimize the Hydrostatic Extrusion, HE, parameters in terms of their influence on the microstructure and certain mechanical properties of 6082 Aluminum alloy. The investigations focused on the fabrication of a nano- or ultrafine-grained microstructure of the alloy. The grain refinement brought about a significant improvement in the microhardness and tensile strength of the alloy.

7) P Widlicki et al.(2006) investigated that 6082 Aluminum alloy combines a good toughness and excellent corrosion resistance with high strength which is why it finds wide use in the building, marine and transport industries and for the fabrication of machined parts for the automotive industry. The high strength condition is achieved conventionally by age or precipitation hardening, or by strain hardening. However, grain refinement obtained by SPD techniques, including hydrostatic extrusion can achieve even greater strength.

8) SKailainathan et al.(2014) evaluated the effect of joining parameters on the mechanical properties of dissimilar Aluminum alloys (AA6063 and AA8011 Aluminum alloy) joints produced using friction stir welding. Friction stir weld was performed on the dissimilar Aluminum alloys using different rotational speeds and traverse speeds and the influence of these parameters on the mechanical performance of the weld has been investigated in terms of hardness and tensile testing. The better value of tensile strength of 134 MPa was obtained at rotational and traverse speed of 1200 rpm and 60mm/min respectively. The hardness of the specimen was found to increase with the increase in rotational speed and transverse speed and reached a maximum of 18 BHN at a rotational and transverse speed of 1000 rpm and 70 mm/min respectively. The increase in rotational speed beyond this critical limit resulted in decrease in hardness.

9) Kumar K, Kailas S V, Arbegast W J (2008) showed Friction stir welding (FSW) is an innovative solid phase welding process in which the metal to be welded is not melted during welding, thus the cracking and porosity often associated with fusion welding processes are eliminated. Therefore, the FSW process can also be used to weld Aluminum alloys in order to obtain high quality joints.

10) N T Kumbhar et al.(2008), Mustafa Kemal Kulakci et al.(2010), L P Troeger et al.(2000) in their research study showed that the mechanical properties of the friction-stir-welded joints have indicated the softening in the joints of the Aluminum alloys such as AA6063 and AA8011 caused
due to dissolution or growth of strengthening precipitates during the welding thermal cycle, thus resulting in the degradation of mechanical properties of the FSW joints. The welding parameters namely rotational speed and traverse speed were considered as the prominent factors which affects the mechanical performance of the welding.

11) Rajan Verma et al.(2016) made an attempt has made to find the conditions like how Welding current, Welding voltage, Welding speed and the gas flow rate will set, optimization method and choice of filler rod under which aluminum 6061 plate will give optimum mechanical properties. Welding Current, Welding Voltage, Gas Flow Rate and Welding Speed are the main influencing parameters, which effect the mechanical properties of aluminum 6061 alloy. Taguchi’s Orthogonal array is very beneficial for optimal selection of above welding parameters. For maximum strength filler rod used should be Er 4043. TIG Welding machine used should be of AC Voltage type.

12) T Senthil Kumar et al.(2006) studied influences of pulsed current TIG welding parameters on the tensile properties of AA6061 aluminum alloy. Pulsed current TIG welding process utilizes arc energy more efficiently by reducing the wastage of heat energy by conduction into the adjacent parent metal. In TIG welding heat required to melt the base metal is supplied only during peak current pulses for brief intervals of time, allows the heat to dissipate leading to a narrower HAZ. The results reveal that the refinement of microstructure is due to pulsed current welding is more compared to conventional continuous current welding. It is also observed that the pulsed current welding also improves mechanical properties like tensile strength & hardness.

13) Wang et al.(2009) did the experiment using He–Ar mixed gas as shielding gas, the tungsten inert gas (TIG) welding of SiCp/6061 Al composites was investigated without and with Al–Si filler. Experiment carried out with plate dimension 60mm X 30mm X 3mm, welding was performed with gas flow rate 115 ml/s, welding speed 18 cm/min and arc length 4 mm. Welded joint with filler were submitted to tensile tests. The microstructure and fracture morphology of the joint were examined. The results show that adding 50 vol.% helium in shielding gas improves the arc stability, and seams with high-quality appearance are obtained when the Al–Si filler is added. The microstructure of the welded joint displays non-uniformity with many SiC particles distributing in the weld center. The average tensile strength of weld joints with Al–Si filler is 70% above that of the matrix composites under annealed condition.

14) Ali M Hatab et al.(2014) the precipitation hardening of the alloy is sluggish and its acceleration would be beneficial in improving the alloy properties. There are several ways to accelerate the precipitation process, fast quench and/or deformations (stretching) are among those processing techniques in producing excess vacancies, which may enhance the transformation rates of precipitating strengthening phases in the alloy. The individual effects of hardening process parameters on aging response and mechanical properties of Al-Mg-Si (6061-type) are carried out by employing Taguchi approach. The obtained mechanical properties of the alloy by running experiment no.1 (aged at 160°C for 5hrs) shows an increase ~19MPa in yield strength, ~11MPa in tensile strength, and no affect on fracture strength when compared with initial condition alloy aged at 160°C for 5hrs. The delay time before (natural aging) deformation is the most contributed parameter, followed by delay time after deformation, quenching media, and the least contributed parameter is the stretching steps in this set of the experiments. The prediction equation can be
used to predict the strength of the alloy for any other combinations of process parameters in this set of experiments.

15) Cheng-Yu Chou et al. (2008) studied the effect of heat treatments on AA6061 Aluminum alloy deformed by cross-channel extrusion (CCE), and they reported that this method enhanced the mechanical properties of the alloy.

16) Niranjani et al. (2009) investigated the development of high strength Al-Mg-Si alloy through cold rolling and aging. They reported that the combination of high strength and ductility could be improved by severe plastic deformation followed by anneal/aging treatment.

17) Dequan Shi et al. (2016) studied the effects of quenching parameters, including the solid-solution temperature, water temperature of quenching, transfer time before quenching and delay time after quenching on the mechanical properties of the 7A04 Aluminum alloy. The experimental results showed that the mechanical properties are relatively stable when the solid-solution temperature is at 460°C–490°C, but the over-burn will appear once the temperature exceeds 500°C. When the water temperature of quenching and the transfer time before quenching are above 40°C and 20 s, the strengths of the 7A04 alloy will drop remarkably. Before the delay time after quenching is 8 h, the strengths will drop gradually while the elongation will rise continuously. In the range of 8 h–24 h there is an opposite change of mechanical properties compared to the previous 8 h. Once it exceeds 24 h, the mechanical properties will become stable.

18) Datau S G (2014) studied the effect of runner size, mould temperature, and pouring temperature on the mechanical properties of aluminum alloy part produced through sand casting. Aluminum alloy scraps of known specification were sourced locally and recycled into cylindrical shapes in a sand mould. Azare foundry sand was used for the production of moulds. The effect of the runner size was studied by tapering the size of the runner towards the mould cavity. The reduced cross-sectional area of the runner is considered. The prepared mould was pre-heated within a temperature range of 25°C—230°C. However, pouring temperature was varied within the range of 700°C—8500°C. The mechanical properties Aluminum alloy castings studied were hardness, impact and tensile strength. The results showed that the selected process parameters significantly influence the mechanical properties of the Aluminum alloy casting. The results of this study can be employed as input data in sand casting process, which is one of the commonest manufacturing methods being practiced in developing countries; so that the high volume of the defective castings usually produced will be reduced, thereby making the process less expensive.

19) Sanders (2001) proposed that casting as a process which involves an interplay between so many parameters such as melting temperature of charge, the mould condition (temperature, moisture content, sand and type of binders used), pouring temperature, and the gating design (i.e. pouring speed, runner size and included gases), the casting size, the type of alloy. The variation in most of these process parameters from their set values can affect the rate of solidification of the molten metal in the mould and this in turn can affect crystals’ formation. In another word, the difference in the microstructure of the casting can result due to the non-uniform cooling of the molten metal in the mould. It is established that to ensure uniform cooling of the molten metal in the mould, the law of uniform flow must be maintained (i.e. constant volume per second flow of the molten
metal during the filling of the mould cavity). The task of ensuring that a uniform microstructure is formed in a casting depends on the ability to maintain a law of uniform flow during the feeding of the mould.

20) Chandan Kaushal et al.(2014) aimed to investigate the effects of Gas Metal Arc Welding (GMAW) on the mechanical properties of different grades of aluminum alloys. GMAW replaces the Tungsten Inert Gas (TIG) method of providing equally high quality of joints with a much higher performance. Aluminum alloys under consideration for this experiment will be from 6XXX series, consisting of Silicon and Magnesium as main alloying elements. The Hardness, Tensile strength, yield stresses and elongation will be the mechanical properties to be obtained. Increasing of the arc voltage and welding current increases the welding heat input: accordingly the chance of defects formation such burn through in weld metal also increases.

21) Elsadig O Eltai and E Mahdi(2013) performed an experiment to find out the effects of MIG welding on the corrosion and mechanical properties of AA6061 T6. Filler wire used for experiment is A404. Specimen were prepared using cutting machine after that a corrosion environment consisting of 3.5% (wt) NaCl in distilled water was prepared and weldments were inserted in solution. To conduct the welding process, commercial welding machine with a capability of changing its electric current was used. Specimens were welded under Ar (99% purity) as a shielding gas. Specimens were welded under Ar (99% purity) as a shielding gas. A current of 110 Ampere using Telwin Master MIG machine was applied. Rockwell hardness test was carried out on circular welded samples with a load of 60 kg, a ball indenter of 1/16 inch diameter, and duration of 15s using Indented hardness tester Model 8187. LKV, UK. The corrosion potential of the HAZ was largely fluctuated over the immersion time showing more negative potential peaks. The hardness of the welded specimens was increased as we moved away from the weld centre even at HAZ. Welded specimens were shown to have lower torsion properties comparing to the non-welded specimens.

3. Conclusion

The processes such as shot peening and age hardening have direct influence on properties like fatigue strength, tensile strength, corrosion resistance keeping few parameters constant. When the temperature and time parameters are optimized, age hardening of Aluminum alloys show maximum tensile strength, yield strength and hardness. Hydrostatic extrusion process brings good improvement in microhardness and tensile strength based on the selected parameters. Various welding and casting process have also shown their influence on considerable improvement of mechanical properties of the alloys.
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