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Classification of Aluminium Alloy Series with its Application and their suitable Welding Techniques

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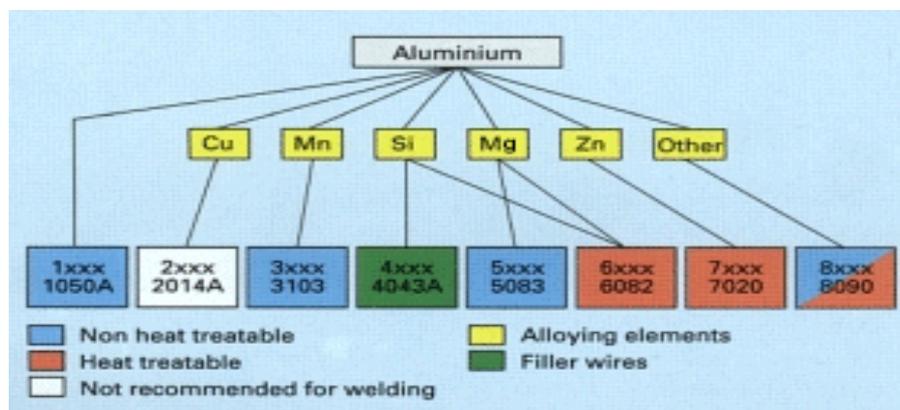
ABSTRACT: Aluminium & its alloys are used in fabrications because of their light weight, good weldability and corrosion resistance. Although normally low strength, some of the more complex alloys can have mechanical properties (Material hardness and strength) equivalent to steels. The various types of aluminium alloys are identified and guidance is given on fabricating components without impairing corrosion and mechanical properties of the material or introducing imperfections into the weld. The common welding techniques use to weld the Aluminium & its alloys.

KEYWORDS: NHTA (non-heat-treatable alloys), HTA (heat-treatable alloys), HAZ (Heat Affected Zone), FSW (Friction Stir Welding), Fusion Welding, porosity, Solidification cracking, Liquation cracking, poor weld bead profile.

I. INTRODUCTION

As *pure aluminium* is relatively very soft. So, some amounts of alloying elements are added to produce a range of mechanical properties. The alloys are grouped according to the principal alloying elements (Like : Cu, Mn, Si, Mg, Zn, etc.), specific commercial alloys have a four-digit designation according to the international specifications for wrought alloys or the ISO alpha - numeric system.

The alloys can be further classified according to the means by which the alloying elements develop mechanical properties, non-heat-treatable or heat-treatable alloys, etc. (as shown in figure)



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II. DESCRIPTION

NHTA (Non-heat-treatable alloys)

{ mainly found in the 1xxx, 3xxx and 5xxx series }

- Material strength depends on the effect of solid solution hardening & work hardening of alloy elements such as Mg (magnesium), and Mn (manganese).
- When welded, these alloys may lose the effects of work hardening which results in softening of the HAZ (Heat Affected Zone) adjacent to the weld.

HTA (Heat-treatable alloys)

{ mainly found in the 2xxx, 6xxx and 7xxx series }

- Material strength & hardness depend on alloy composition and heat treatment (Like : quenching , normalizing, etc).
- Principal alloying elements are Cu (Copper), Mg₂Si (Magnesium and Silicon), Zn (Zinc) .
- Fusion welding redistributes the hardening constituents in the HAZ (Heat Affected Zone) which locally reduces the material strength.

The principal effects of alloying elements in aluminum are as follows :

- **Copper (Cu), 2xxx** – The aluminum-copper alloys typically contain between 2 to 10% copper, with smaller additions of other elements. The copper provides substantial *increases in strength and facilitates precipitation hardening*. The introduction of copper to aluminum can also *reduce ductility and corrosion resistance*. The susceptibility to solidification cracking of aluminum-copper alloys is increased; consequently, some of these alloys can be the most challenging aluminum alloys to weld. These alloys include some of the highest strength heat treatable aluminum alloys.

The most common applications for the 2xxx series alloys are aerospace, military vehicles and rocket fins.

- **Manganese (Mn), 3xxx** – The addition of manganese to aluminum *increases strength* somewhat through solution strengthening and *improves strain hardening* while not appreciably *reducing ductility or corrosion resistance*. These are moderate strength non heat-treatable materials that retain strength at elevated temperatures and are seldom used for major structural applications.

The most common applications for the 3xxx series alloys are cooking utensils, radiators, air conditioning condensers, evaporators, heat exchangers and associated piping systems.

- **Silicon (Si), 4xxx** – The addition of silicon to aluminum *reduces melting temperature and improves fluidity*. Silicon alone in aluminum produces a non heat-treatable alloy; however, in combination with magnesium it produces a precipitation hardening heat-treatable alloy. Consequently, there are both heat-treatable and non heat-treatable alloys within the 4xxx series. Silicon additions to aluminum are commonly used for the manufacturing of castings.

The most common applications for the 4xxx series alloys are filler wires for fusion welding and brazing of aluminum.

- **Magnesium (Mg), 5xxx** - The addition of magnesium to aluminum *increases strength through solid solution strengthening and improves their strain hardening ability*. These alloys are the highest strength non heat-treatable aluminum alloys and are, therefore, used extensively for structural applications. The 5xxx series alloys are produced mainly as sheet and plate and only occasionally as extrusions. The reason for this is that these alloys strain harden quickly and, are, therefore difficult and expensive to extrude.

Some common applications for the 5xxx series alloys are truck and train bodies, buildings, armored vehicles, ship and boat building, chemical tankers, pressure vessels and cryogenic tanks.

- **Magnesium and Silicon (Mg₂Si), 6xxx** – The addition of magnesium and silicon to aluminum produces the compound magnesium-silicide (Mg₂Si). The formation of this compound provides the 6xxx series their *heat-treatability*. The 6xxx series alloys are easily and economically extruded and for this reason are most often found in an extensive selection of extruded shapes. These alloys form an important complementary system with the

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5xxx series alloy. The 5xxx series alloy used in the form of plate and the 6xxx are often joined to the plate in some extruded form.

Some of the common applications for the 6xxx series alloys are handrails, drive shafts, automotive frame sections, bicycle frames, tubular lawn furniture, scaffolding, stiffeners and braces used on trucks, boats and many other structural fabrications.

- **Zinc (Zn), 7xxx** – The addition of zinc to aluminum (in conjunction with some other elements, primarily magnesium or copper) produces *heat-treatable aluminum alloys of the highest strength*. The zinc substantially *increases strength and permits precipitation hardening*. Some of these alloys can be susceptible to stress corrosion cracking and for this reason are not usually fusion welded. Other alloys within this series are often fusion welded with excellent results.

Some of the common applications of the 7xxx series alloys are aerospace, armored vehicles, baseball bats and bicycle frames.

- **Iron (Fe)** – Iron is the most common impurity found in aluminum and is intentionally added to some pure (1xxx series) alloys to *provide a slight increase in strength*.
- **Chromium (Cr)** – Chromium is added to aluminum to control grain structure, to *prevent grain growth in aluminum-magnesium alloys*, and to *prevent re-crystallization in aluminum-magnesium-silicon* or aluminum-magnesium-zinc alloys during heat treatment. Chromium will *also reduce stress corrosion susceptibility and improve toughness*.
- **Nickel (Ni)** – Nickel is added to aluminum-copper and to aluminum-silicon alloys to *improve hardness and strength at elevated temperatures* and *to reduce the coefficient of expansion*.
- **Titanium (Ti)** – Titanium is added to aluminum primarily as a grain refiner. The *grain refining effect* of titanium is enhanced if boron is present in the melt or if it is added as a master alloy containing boron largely combined as TiB₂. Titanium is a common addition to aluminum weld filler wire as *it refines the weld structure and helps to prevent weld cracking*.
- **Zirconium (Zr)** – Zirconium is added to aluminum *to form a fine precipitate of inter-metallic particles that inhibit re-crystallization*.
- **Lithium (Li)** - The addition of lithium to aluminum can substantially *increase strength and, Young's modulus, provide precipitation hardening and decreases density*.
- **Lead (Pb) and Bismuth (Bi)** – Lead and bismuth are added to aluminum *to assist in chip formation and improve machinability*. These free machining alloys are often not weldable because the lead and bismuth *produce low melting constituents* and can *produce poor mechanical properties* or *high crack sensitivity on solidification*.

FILLER ALLOYS

Filler metal composition is determined by:

- weldability of the parent metal
- minimum mechanical properties of the weld metal
- corrosion resistance
- anodic coating requirements

Nominally matching filler metals are often employed for NHTA (non-heat-treatable alloys). However, for alloy-lean materials and HTA (heat-treatable alloys), non-matching fillers are used to prevent solidification cracking.

COMMON WELDING TECHNIQUE:

Mostly two types of welding techniques are used for Aluminium & it's alloys:

- **Fusion welding**
- **FSW(friction stir welding)**

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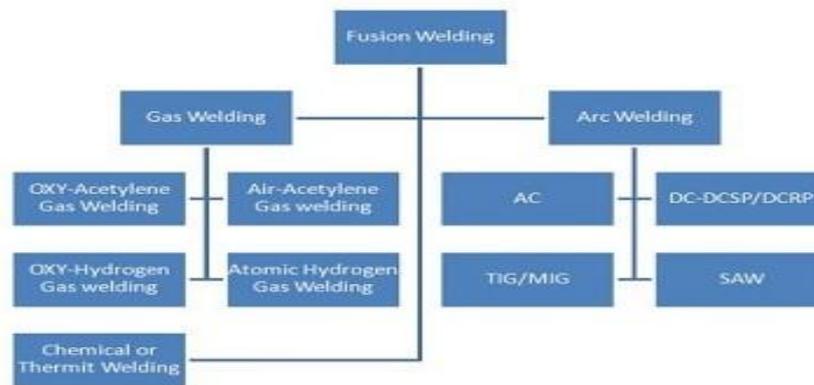
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FUSION WELDING

Fusion welding is a generic term for welding processes that rely on melting to join materials of similar compositions and melting points. Due to the high-temperature *phase transitions* inherent to these processes, a *heat-affected zone* is created in the material (although some techniques, like beam welding, often minimize this effect by introducing comparatively little heat into the workpiece).

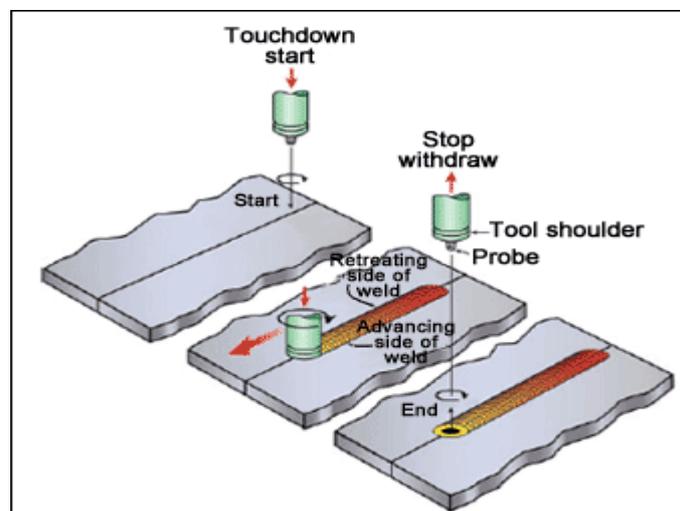
In contrast to fusion welding, solid-state welding does not involve the melting of materials.



Fusion Welding Process is further classified as:

- i. **Gas Welding Process:**By burning of gases, if the heat required for melting of plates is obtained called as Gas welding operation.
- ii. **Arc Welding Process:**By using electric arc, if the heat required for melting of plates is obtained called as Arc Welding Operation.
- iii. **Chemical Welding Process:**By using Exothermic Chemical Reaction, if the heat required for melting of plates is obtained called as Chemical welding process.

FRICITION STIR WELDING(FSW)



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Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough. It was primarily used on wrought or extruded **aluminium** and particularly for structures which need very high weld strength. FSW is capable of joining aluminium alloys, copper alloys, titanium alloys, mild steel, stainless steel and magnesium alloys. More recently, it was successfully used in welding of polymers. In addition, joining of dissimilar metals such as aluminium to magnesium alloys has been recently achieved by FSW. Application of FSW can be found in modern **shipbuilding, trains, and aerospace applications**.

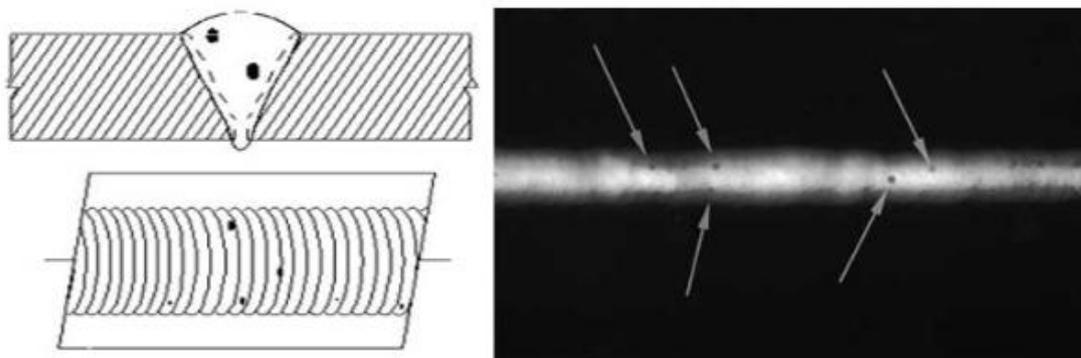
It was invented and experimentally proven at *The Welding Institute* (TWI) in the **UK** in December 1991. TWI held patents on the process, the first being the most descriptive.

DEFECTS /IMPERFECTIONS IN WELDS

Aluminium & its alloys can be readily welded providing appropriate precautions are taken. The most likely imperfections in fusion welds are:

- porosity
- Solidification cracking
- Liquation cracking
- poor weld bead profile

● Porosity



Porosity is often regarded as an inherent feature of MIG welds; typical appearance of finely distributed porosity in a TIG weld is shown in the photograph. The main cause of porosity is absorption of hydrogen in the weld pool which forms discrete pores in the solidifying weld metal. The most common sources of hydrogen are hydrocarbons and moisture from contaminants on the parent material and filler wire surfaces, and water vapour from the shielding gas atmosphere. Even trace levels of hydrogen may exceed the threshold concentration required to nucleate bubbles in the weld pool, aluminium being one of the metals most susceptible to porosity.

To minimise the risk, rigorous cleaning of material surface and filler wire should be carried out. **Three cleaning techniques are suitable:**

- 1. mechanical cleaning :** Wire brushing (stainless steel bristles), scraping or filing can be used to remove surface oxide and contaminants. Degreasing should be carried out before mechanical cleaning.
- 2. solvent degreasing:** Dipping, spraying or wiping with organic solvents can be used to remove grease, oil, dirt and loose particles.
- 3. chemical etching / etch cleaning:** A solution of 5% sodium hydroxide can be used for batch cleaning but this should be followed by rinsing in HNO₃ and water to remove reaction products on the surface.

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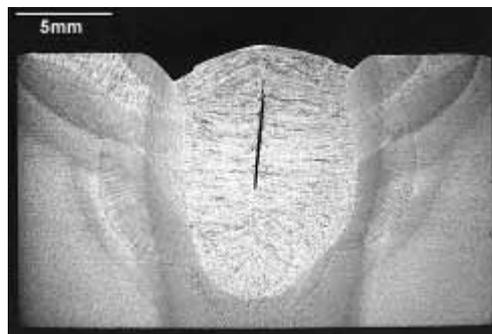
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In *gas shielded welding*, air entrainment should be avoided by making sure there is an efficient gas shield and the arc is protected from draughts. Precautions should also be taken to avoid water vapour pickup from gas lines and welding equipment; it is recommended that the welding system is purged for about an hour before use.

● Solidification cracks



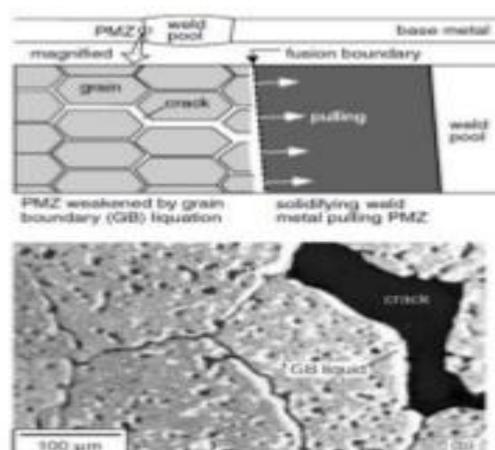
Cracking occurs in aluminium alloys because of high stresses generated across the weld due to the high thermal expansion (twice that of steel) and the substantial contraction on solidification - typically 5 % more than in equivalent steel welds.

Solidification cracks form in the centre of the weld, usually extending along the centreline during solidification. Solidification cracks also occur in the weld crater at the end of the welding operation. The main causes of solidification cracks are as follows:

- incorrect filler wire/parent metal combination
- incorrect weld geometry
- welding under high restraint conditions

The cracking risk can be reduced by using a non-matching, crack-resistant filler (usually from the 4xxx and 5xxx series alloys). The disadvantage is that the resulting weld metal may have a lower strength than the parent metal and not respond to a subsequent heat treatment. The weld bead must be thick enough to withstand contraction stresses. Also, the degree of restraint on the weld can be minimised by using correct edge preparation, accurate joint set up and correct weld sequence.

● Liquation cracking



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Liquation cracking occurs in the HAZ, when low melting point films are formed at the grain boundaries. These cannot withstand the contraction stresses generated when the weld metal solidifies and cools. Heat treatable alloys, particularly 6xxx and 7xxx series alloys, are more susceptible to this type of cracking.

The risk can be reduced by using a filler metal with a lower melting temperature than the parent metal, for example the 6xxx series alloys are welded with a 4xxx filler metal. However, 4xxx filler metal should not be used to weld high magnesium alloys (such as 5083) as excessive magnesium-silicide may form at the fusion boundary decreasing ductility and increasing crack sensitivity.

● Poor weld bead profile

Incorrect welding parameter settings or poor welder technique can introduce weld profile imperfections such as lack of fusion, lack of penetration and undercut. The high thermal conductivity of aluminium and the rapidly solidifying weld pool make these alloys particularly susceptible to profile imperfections.

III. RELATED WORK

The main objective of this paper is to explain the classification, applications of aluminium alloys in a proper manner. In comparison to other papers, this paper has a very special application. For every alloy there is a specific feature and each alloy has its own welding technique, this paper explains the welding technique to the specific alloy respectively.

IV. RESULTS

Most of the wrought grades in the 1xxx, 3xxx, 5xxx, 6xxx and medium strength 7xxx (e.g. 7020) series **can be fusion welded using TIG, MIG and oxy-fuel processes**. The 5xxx series alloys, in particular, have excellent weldability.

High strength alloys (e.g. 7010 and 7050) and most of the 2xxx series are not recommended for fusion welding because they are **prone to liquation and solidification cracking**.

FSW (Friction Stir Welding) is particularly suited to aluminium alloys because it is capable of producing sound welds in many alloys, including those heat treatable alloys which are **prone to hot cracking during fusion welding**.

V. CONCLUSIONS

In this paper, the several available types of aluminium alloys were presented and explained. Each series of the aluminium alloy is based on its alloying element. There were 3 main types of all the series in aluminium alloy which includes **pure aluminium, heat treatable aluminium alloy and non-heat treatable aluminium alloy**. Due to the great and versatile properties of aluminium alloy, the demand of usage for the aluminium alloy had improved vastly in so many applications. The two main industries that benefit most from aluminium alloys were the **automotive and aerospace industries**. The use of aluminium alloys ensure brighter future since its usage is almost limitless and ensures a more sustainable and greener environment.

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