Nat. Volatiles & Essent. Oils, 2021; 8(5): 3563 - 3593

Investigation on Hot Cracking of Aluminum 7xxx Alloy Using Gas Tungsten Arc Welding

[1]Pratheesh kumar S, [2]Elangovan S, [3]Arun Srinivasan R
[1,2,3] Department of Production Engineering, PSG College of Technology, Coimbatore, India-614004
Corresponding author email id: spratheeshkumarth@gmail.com

Abstract

Food packaging, structural components in the aerospace industry, and other uses for aluminized aluminium alloys are just a few of the many uses for this abundant metal. Because of its low weight, moderate strength, and high corrosion resistance, aluminium and its alloys have found widespread use in a wide range of industries. Aluminum alloys of the 7xxx series have superior mechanical qualities when compared to other aluminium alloy series. The alloy AA7075 is utilised in the structure of aircraft wings. When fusion welding is used to combine certain alloys, they are more prone to solidification or hot cracking. The alloying components present contribute to these alloys' high crack sensitivity. Thus, a rigorous analysis has been undertaken in this project effort to determine how to reduce the susceptibility of the alloy 7075 to hot cracking by adjusting the composition without affecting the mechanical qualities. A thorough background study has been conducted on the effect of hot cracking on the aluminium alloy AA7075, and a methodology for overcoming this welding defect has been developed. This methodology includes altering the composition of the major alloying elements in AA7075 and stabilising the composition for the development of a new alloy. Experiments were conducted and alloys were cast with a predetermined composition. The samples were subjected to a hot cracking test, and the sample with the best result had its mechanical properties determined. The test results were compared to those obtained with AA7075 and discussed in this paper.

Keywords : *Gas tungsten arc welding, Solidification.*

I.INTRODUCTION

A non-consumable tungsten electrode is used to weld a seam together using the gas tungsten arc welding process (GTAW). With the use of an inert gas, the electrode may be kept free of contamination while also helping to keep it from oxidising. Using tungsten electrodes and no consumables, geothermal arc welding (GAW) is a welding technique also known as tungsten inert gas welding (TIG). By using an inert gas, the weld zone and electrode are shielded from oxidation and other air pollution. Aluminium is a common substance because it makes up 8% of the earth's crust. Also, after steel, it is the second most important metal economically. Aluminum was discovered by Sir Humphrey Davy in 1808 and is still in use today despite the fact that copper, lead, and tin have been around for a very long time [1]. For the first time, in 1886, chemists Charles Martin Hall in the United States and Paul Heroult in France developed industrial processes for the electrolytic reduction of alumina (Al2O3) into aluminium, establishing the metal's economic potential for engineering purposes. This priceless metal has the radiance of silver, the indestructibility of gold, the hardness of iron, the flammability of copper, and the lightness of glass, among other properties. Our hypothesis states that it was made particularly to provide us with raw material for our projectile, and that it is three times lighter than iron. It can be easily wrought, extensively distributed, and makes up a large portion of rocks; it is three times lighter than iron. Aside from having a low density (about one-third that of steel), good ductility, high thermal and electrical conductivity, and exceptional corrosion resistance, aluminium also has a lovely appearance and is completely free of harmful substances [2] [3]. Aluminum, on the other hand, is a non-toxic metal. To make place for fuel-efficient engines, vehicle constructions such as vehicles and trucks use aluminium, which is why metal is widely used in transportation and building.

A. Al-Zn-Mg Alloy System

These alloys are "heat treatable," which means that they may be strengthened by applying heat, due to the inclusion of zinc (which is typically between 4 and 6 percent by weight) and magnesium (which is typically between 1 and 3 percent by weight) (precipitation hardening). Stress corrosion appears to be a problem with certain alloys, which is regrettable. Aerospace, space exploration, military, and nuclear power generating all use these alloys because of their exceptional strength. Structural components for construction and high-strength sporting equipment, such as ski poles and tennis rackets, can be made with the 7xxx series.

To boost age-hardening potential, alloys in the 7xxx and 2xxx series contain magnesium as precipitating phases, with the most common form being MgZn2 (magnesium zinc oxide) (magnesium zinc oxide). Alloys containing aluminium, zinc, and magnesium have stronger heat resistance and, as a result, higher theoretical strengths than binary alloys just containing aluminium and zinc. When it comes to improving corrosion resistance, metals like zinc and magnesium are better choices than stainless steel. Copper and trace amounts of chromium and manganese are added to aluminum-zinc-magnesium alloys to increase their strength. This results in the strongest aluminium alloys currently accessible. Alloys based on the quaternary Al–Zn–Mg–Cu system have the highest age-hardening potential of any aluminium alloy, exceeding the potential of any other aluminium alloy. Zinc and magnesium are inorganic compounds that regulate the ageing process, while copper affects the ageing rate as well as the material's quench sensitivity [4]. It's a common misconception that copper decreases total corrosion resistance while increasing stress corrosion resistance. If silicon and iron are added to zinc-containing alloys, the results can be incredibly strong and fracture-resistant metals. Although precipitation hardening is feasible when magnesium is coupled with the alloy, the alloy becomes prone to stress corrosion when more than ten percent Zn is included in the composition. Additionally, the addition of zinc to aluminium improves the material's ability to solve problems and is more durable. Protection cladding (7072), as well as sacrificial anodes, are two applications for this material. A fault known as "hot cracking," "solidification cracking," or "shrinkage brittleness" is very common in aluminium alloys, yet despite this, the alloys are highly resistant to these defects. These alloys are used in automotive engineering applications that require welding. It is possible to develop this severe fault during solidification (solidification cracking) or remelting, provided that the solidus temperature does not rise above the solidus temperature (liquation cracking). When present, it causes mechanical qualities to deteriorate and is responsible for the costly loss of faulty materials as a result of corrosion. For example, the use of high-strength aircraft aluminium alloys such as Alloy 7075 and 2024 in spaceship construction is a noteworthy exception to this rule. Due to the high susceptibility of some metals to solidification cracking, welding particular alloys may be prohibited due to the significant risk of solidification cracking. A great deal of work is devoted in research to increase the weldability of aluminium alloys, which are directly competitive with high strength steels in terms of strength, as a result.

B. Solidification Cracking

AA7075, an aluminium alloy with great strength, is utilised in the construction of aircraft wing structures and fuselage tanks, where it must be welded to other aluminium components. Cracks are one of the most frequently encountered issues when welding aluminium alloys, and they can be rather severe. The term "hot cracks" refers to fractures that occur more frequently in the natural environment and are therefore more dangerous to humans. For hot cracking to occur there must be a combination of mechanical, thermal, and metallurgical variables working together. Weld metal can also produce intercrystalline solidification fractures and liquidation cracks in the Heat Affected Zone (HAZ). The solidification or hot cracking of certain alloys is more likely to occur when they are welded together while heated. In solidification, the hot crack occurs when the alloy's ductility temperature drops to an unusually low level, triggering the fracture. Solidification cracking occurs when thermal tensile strains from internal contraction and external displacement exceed the minimum tolerated strain required to start cracking. This temperature range is where cracking begins. When a low degree of ductility and heat strain are combined, it results in the formation of a solid state. The addition of alloying elements increases the crack sensitivity of these alloys [5] [6], which is a result of the incorporation of these components. According to the findings of a study conducted on this subject, changing the chemical composition of AA7075 can help to reduce the problem of hot cracking that occurs during the fusion welding process. A process for measuring the susceptibility of materials to heat cracking, the Houldcroft test, was used to validate the benefit of altering the chemical composition of the material under consideration.

Making a systematic search for and reading documents that contain information about the issue under consideration is the process of conducting a literature survey. It contains articles, abstracts, reviews, and other monthly reports, among other things. In order to critically summarise current knowledge in the issue under examination and to evaluate the strengths as well as limitations of prior work in the field, it is necessary to conduct a literature review. An examination of more than 40 articles published between 1999 and 2015 led to the conclusion that 13 publications issued between 1999 and 2015 were closely related to the project's activities. This chapter analyses in depth the findings of the research efforts described in those papers, as well as the implications of those findings. It has been reported that a journal article written by Dursun and Soutis (2014) [7] was published in which they discussed the most current breakthroughs in advanced aircraft aluminium alloys, which was written by Dursun and Soutis (2014). The most recent advances in improving the mechanical properties of aluminium alloys, as well as the development of high-performance joining procedures, will be discussed. It was found that mechanical properties of newly created aluminium alloys, such as those from the 2xxx and 7xxx series and new generation Al–Li alloys, were better than those of conventional aluminium alloys in this study. Upper and lower wing structures, as well as the fuselage tank, are typical aerospace applications for aluminium from the 7xxxxxx series. In addition to weld cracking and distortion due to residual stresses caused by aluminum's high coefficient of thermal expansion, high thermal conductivity of aluminium requires a large welding heat input, which increases the likelihood of distortion and cracking, and weld cracking due to aluminium solidification shrinkage are all manufacturing difficulties associated with fusion welding methods for these alloys. Furthermore, the benefits and drawbacks of laser beam and friction stir welding are carefully analysed. Laser beam and friction stir welding When welding high strength aluminium alloys, problems can develop, as Wei Zhou (1999) [8] discovered. An in-depth look is given into how different alloying elements affect aluminium alloy physical qualities and thermal treatment in the 5xxx and 7xxx series in this research. A discussion of inert gas tungsten arc welding (GTAW or TIG), inert gas metal arc welding (GMAW or MIG), and three challenges that can emerge while welding high strength aluminium alloys will be presented in this article. The heat affected zone is a result of partial melting at grain boundaries due to low melting temperatures produced by chemical segregation and chemical compositions of the base metal, as well as porosity, stress corrosion cracking, hot cracking in the weld bead, and the heat affected zone. Reduce thermal contraction stresses and change the chemical composition of the weld metal are also suggested as preventive strategies in order to minimise failure risk. A number of the alloys' low weldability can be traced back to factors such as poor solidification microstructure, porosity in the fusion zone, and mechanical property loss when welded using conventional fusion welding techniques and friction stir welding, as reported by Kumar et al. (2015) [9] in a journal on Microstructure, mechanical, and corrosion behaviour of high strength AA7075 Aluminum alloy friction stir welds. The microstructural changes in the weld nugget following TIG welding make the welds more corrosive, according to recent research. A revolving tool stirs the material, subjecting it to strong plastic deformation at high temperatures, and the varying microstructure causes AA7075 aluminium weld's hardness and corrosion resistance to vary. A weak HAZ is a contributing factor in the AA7075 aluminium weld's poor corrosion resistance. Because the FSW method has a significant impact on microstructures, the book goes into great detail about these difficulties. The microstructural and hardness evolutions following heat treatment prior to and following welding, as well as the hardness evolution following heat treatment prior to an arc weld, were explained by Maamar and colleagues (2008) [10] in a journal article on the effects of heat treatment and welding on the mechanical properties and microstructure evolution of the 2024 and 7075 aluminium alloys. Several different temperature and current levels, as well as various time periods, were investigated in this study. The fusion barrier is protected from damage during welding by a liquid layer formed at grain boundaries next to the fusion barrier. These liquid layers generate small intergranular fractures after welding, which can lead to brittle intergranular fracture in the underlying material.. after welding.. Research shows that current parameter ranges of 400–440 are the most effective, while voltage parameter ranges of 42.5–42.7 are the most successful.

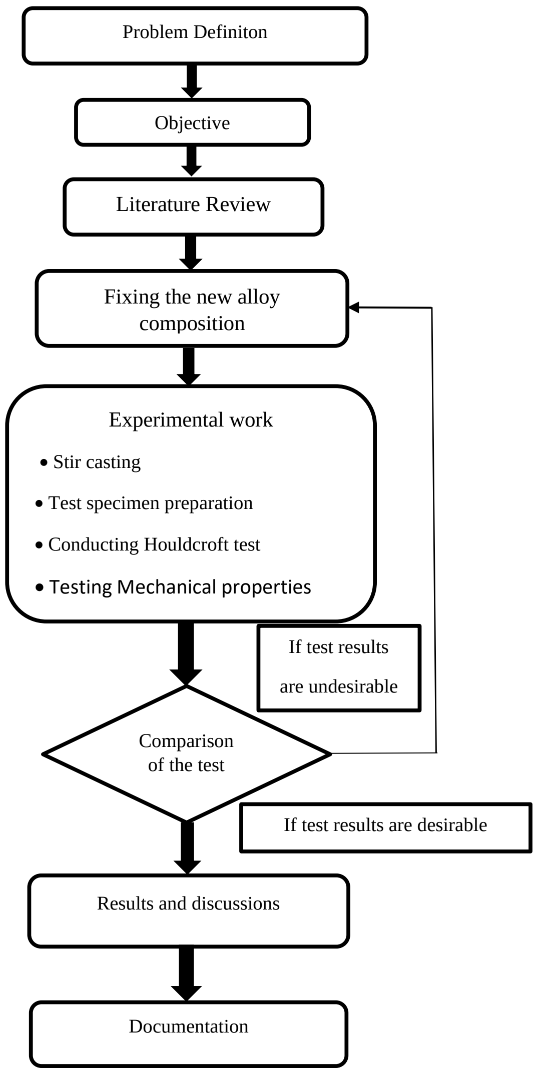
When Bertram et al. (2008) [11] submitted their thesis titled Identification of Weld Solidification Cracking Mechanisms via Novel Experimental Techniques and Model Development, they looked at the weldability of an aluminium alloy. The goal of this thesis is to discover how and why 6060/4043 aluminium weld solidification fractures develop. Al-magnesium-silicon extrusion alloy 6060 is only regarded weldable if a suitable filler alloy, such as 4043 (Al-5Si), is used with the stainless steel alloy. Research was done to see how dilution of 4043 filler affected the sensitivity of Alloy 6060 welds to cracking and how well they solidified. In order to establish methodologies for the onset and advancement of solidification cracks, researchers develop a cracking model at the end of their research. Using multiple metrics, Niel et al. (2013)

[12] show how hot ripping with the material's characteristic length affects the material's characteristic length in their article "Hot-crack test for aluminium alloys welds using TIG method." Increasing the weight percent of a given material can improve weldability, which is an old idea. Weld travel speed, weld pool impurities (Fe, O, and H), and grain refiner additives ($TiAl_3$ + Boron) that affect hot cracking can all be combined into a single experiment. Each parameter's impact on cracking susceptibility might be quantified by varying each one separately and comparing the results to various strain rate–composition combinations. Here, thermal (heat input, cooling rate) and mechanical (restraint intensity) aspects of the Solidification Cracking Phenomenon are explored, together with metallurgical (strain distribution around the weld). Temperature (heat input and cooling rate) and mechanical (restraint intensity) parameters can all affect an alloy's breaking susceptibility. But metallurgical parameters are the most critical. There is evidence in this study that adding significant alloying elements like silicon and copper to the melted alloy enhances its viscosity while diminishing its castability and solidification pathway. They are continuing their inquiry into the microstructure and mechanical properties of GTAW and GMAW joints on AA7075 aluminium alloy by using experiment methodologies, as done by Sivashanmugam and colleagues (2010) [13]. The tensile strength, hardness, and impact strength of the joint were all measured and studied mechanically. Metallographic processes are utilised to identify the fracture properties of the joint under study, as well as microstructure characterizations. There have been numerous studies done on the welding of AA7075, and the results show that the GMAW approach yields lower strength than the GTAW method. WM has a lower hardness value than HAZ and BM, according to the values and the rise in strength value, because WM is a weld. In the GTAW, the hardest areas are those that have been heat-impacted; these have a hardness of 457 VHN, indicating great hardness. There are 453 VHN atoms in the parent metal. In terms of hardness, the GMAW heat-affected zone was found to have a value of 433 (very hardness). Metals with a high valence have a VHN greater than 400, which denotes rarity. Using tungsten inert gas welding, Temmar et al. (2011) [14] looked into the effect of post-weld ageing on the mechanical properties of a low-thickness 7075 aluminium alloy and reported their findings. When there is a significant amount of heat stress and solidification shrinkage present during the various stages of the weld's solidification, they can both produce cracking in aluminium welds. The fusion barrier is protected from damage during welding by a liquid layer formed at grain boundaries next to the fusion barrier. The welded 7075 aluminium alloy has extraordinarily low tensile and impact energy values due to the formation of liquid layers during the welding process. Gas metal arc welding provides a higher deposition rate, welding speed, and penetration depth than other welding processes because of the high heat input. TIG welding is used to build the joints, eliminating the need for filler material in the finished product. During this experiment, an argon shielding gas was used as a protective gas. When it comes to making high-quality welds, TIG welding is preferred over gas metal arc welding because of its versatility. Aluminum alloys and aluminium alloy composite materials undergo microstructural and mechanical changes due to alloying elements, as demonstrated in a recent scientific publication by Rana and colleagues (2012) [15]. The microstructures and mechanical properties of aluminium alloys and aluminium alloy composites are studied in this work as a result of interactions between alloying components. This is largely because of the presence of silica, which is responsible for the outstanding castability (high fluidity, low shrinkage) of the cast component, as well as its low density and light weight, both of which aid in the decrease of the component's overall weight. To improve ultimate tensile strength, silicon content can be increased from

3% to 8% by weight. The corrosion resistance, weldability, and overall strength of the material are all improved with more magnesium concentration. Magnesium concentration in aluminium composites should be between 4 and 8 percent by weight, according to study, at which point the composites display amazing thermomechanical characteristics.. The microstructure and hardness of aluminium copper magnesium alloys are discussed in detail in a paper written by Nafsin and Rashed (2013) [16] and published in the journal. Rashed and Nafsin The article explains how different alloying elements are added to aluminium to improve the material's mechanical qualities. Aluminum-copper-magnesium alloys' cold deformation behaviour and microstructure are being studied in this study. Precipitation hardening can be utilised to increase the alloy's strength up to a copper concentration of 42 percent by weight. It can be used with or without magnesium to boost the alloy's strength. It is possible to improve the strength and hardness of aluminium copper alloys by introducing magnesium, which is the primary benefit of doing so This work is primarily concerned with the impact of microstructural changes on aluminium alloy deformation. Magnesium concentration increases in direct proportion to deformation amount, increasing hardness of the material. Magnesium content rises with stone hardness, therefore harder stones contain more of it. On their study, Verma et al. (2013) [17] explored the impact of silicon and copper content variations in aluminium, silicon, and copper alloys in great detail. They were made using an aluminum-silicon-copper alloy having roughly 5% silicon weight, and their mechanical properties were studied to see how copper composition affected them, and their findings were then published in this publication. Because of the addition of silicon, an alloy's corrosion resistance is greatly improved. There is evidence that magnesium increases the tensile strength of various alloys over time. By increasing the density, magnesium improves the damping qualities of Al-Si-Cu alloys. The alloys' tensile strength was greatly improved because to the inclusion of zinc. AMMC is made for stir casting using the plunger approach demonstrated by Samal et al. (2013). In order to achieve uniform distribution and little porosity in the end result, a plunger rod was used to introduce an aluminummagnesium alloy matrix into this journal, which was extensively documented. It is possible to recover nearly all of the magnesium (95 percent) used in the alloying process because it is stored in mild steel capsule plunger rods and injected directly into the aluminium melt. If the improved stir-casting process is compared to other methods, it was found to be simple and trouble-free to run while also being extremely efficient and, most importantly, cost-effective. Weldability test of precipitation hardenable aluminium alloy EN AW 6082 T6 described by Kolarik and colleagues (2011) was published in the International Journal of Welding. This book addresses the weldability of precipitation hardenable aluminium alloys, which are widely employed in the manufacture of rolling stock and are discussed in detail in the following chapters: During the GTAW and GMAW welding operations, the Houldcroft weldability test was utilised to determine whether the base metal was crack sensitive. According to the results of extensive study, it has been discovered that the GTAW welding technique is substantially more sensitive than the GMAW welding technique when it comes to identifying the susceptibility to solidification cracking.

AA7075 acts as aircraft wing structures and fuselage tanks, where it is welded together to provide strength. Aluminium alloys are particularly prone to the phenomena known as hot ripping. When the liquid content of the mushy zone becomes insufficient, the hot tearing phenomenon frequently occurs in conjunction with a loss of ductility in the mushy zone. This alloy contains a considerable number of critical alloying elements in its crack sensitive zone, making it extremely prone to heat cracking during fusion welding. As a result, friction stir welding is still widely used, despite its drawbacks, which include microstructure differences that cause HAZ to soften, poor corrosion resistance, and process complexity. Zinc is the principal alloying element in AA7075, with magnesium, silicon, and copper serving as secondary alloying elements. AA7075 is a heat treatable alloy that can be mechanically reinforced by the use of a heat treating furnace.

II. EXPERIMENTAL METHODS AND MATERIALS



In this project work, the hot cracking sensitivity on AA7075 is investigated by varying the Mg and Si content in AA7075. This work is planned in three stages.

A. *Alloy Development*

To reduce the susceptibility of AA7075 to heat cracking, the alloy composition was altered by adjusting the magnesium and silicon concentrations, and the alloys were cast using the stir casting technique.

B. Specimen Preparation

When the Houldcroft test specimens were developed, they were used to determine the cracking tendency of sheet materials exposed to GTAW without filler material under high restriction.

C. Houldcroft Test

An aluminium alloy weldability test called the Houldcroft test and a process for doing it were created to go along with it. This test was used to determine the weld's cracking susceptibility, which may be expressed as the length of the fracture divided by the length of the weld. The welding parameters are selected so that the process has complete penetration. This experiment measures the fracture length and uses that data to calculate crack sensitivity (A) and compare the solidification cracking susceptibilities of various compositions. The final section summarises the most important discoveries and lays forth a study plan for the future.

III.PRELIMINARY STUDIES AND SELECTION OF ALLOY COMPOSITION

The parameters affecting the weldability of aluminium alloys have been covered in this article. An overview of the influence of alloying elements, several weldability tests, and the weldability of 7xxx aluminium alloys will be provided.

A. Effect Of Alloying Elements

The major alloying elements present in AA7075 are magnesium, zinc, silicon, copper and manganese. The minor alloying element does not have any effect on the welding.

1) Effect of Magnesium Addition

- By functioning as a surface-active agent, it can improve the corrosion resistance and weldability of aluminium.
- Additionally, it was used to keep graphite particles from clumping together and to improve the aluminium matrix's mechanical qualities, among other things.
- The ideal magnesium content in aluminium was determined to be 4–8 weight percent, and as a result, it exhibited outstanding thermomechanical properties.

2) Effect of Zinc Addition

- It has been observed that Zn-containing alloys can produce precipitates with a high density; an alloy containing 1.8 percent Zn, for example, can produce rod-like precipitates.
- Aalloy with a 1.5 percent zinc addition had the highest ultimate tensile strength.

- The alloy's fracture strength improves with the amount of zinc added.

3) *Effect of Silicon Addition*

- Because of the low density (2.34g/cm3) and strong castability of the cast component, which results in a reduction in the total weight of the cast component, silicon is principally responsible for the cast component's low weight.
- It precipitates as silicon dioxide, which is extremely hard and increases abrasion resistance by a factor of two due to silicon's low solubility in aluminium.
- The addition of silicon reduces the thermal expansion coefficient of Al-Si alloys by a factor of two. Adding silicon to aluminium causes the metal's machinability to be less than desirable.
- According to the manufacturer, increasing the silicon concentration from 3 percent to 8 percent results in a marginal gain in ultimate tensile strength.
- Al-silicon composites can have their thermal conductivity and thermal conductivity improved while their elastic modulus and thermal dimensional stability are reduced by increasing the silicon content.

4) *Effects of Copper Addition*

- Adding copper as the primary alloying element (often 3–6 wt. percent, but it can be considerably higher) with or without magnesium (typically 0–2 percent) results in precipitation hardening of the steel. As a result of the material strengthening that has been done, extremely strong alloys have been produced.
- The presence of copper, on the other hand, has a negative impact on the corrosion resistance of a material.
- Cu is added to the alloy, and this enhances the fatigue qualities, high-temperature properties, and machinability of the alloy.
- Increased strength and hardness are achieved by incorporating magnesium into aluminum-copper alloys, which can be further enhanced through solution heat treatment and quenching.
- The homogenised aluminum-copper-magnesium alloy becomes harder once copper and magnesium are added.

5) *Effect of Manganese Addition*

- The yield strength and ultimate tensile strength of aluminium alloys rise considerably without compromising ductility when manganese is added in excess of 0.5 weight percent.
- As an added bonus, manganese has a higher corrosion resistance than most other elements.

B. Weldability Test

AWS defines it as "a material's capacity to weld into a specific suitably planned structure and to function well in the intended service" when made under precise fabrication conditions. conditions. (AWS). Weldability is affected by many factors, including the process, operating parameters (particularly net linear heat input), procedures, the degree of constraint applied, and the environment (particularly the presence of hydrogen in any form of water or hydrocarbon). However, the chemical composition of the base metal is by far the most important. The composition of an alloy affects weldability; some alloys are naturally weldable, while others are notoriously difficult to weld due to their composition. While welding inherently tough materials, it is vital to pay great attention to the welding conditions, notably the degree of constraint, as well as the overall amount of heat given to the junction. Materials (or assemblies) that cannot be welded must be joined using another method. Weldability testing can be carried out using either direct welding or indirect welding techniques. Direct welding is the most common type of welding test.

For direct weldability tests, you must use a real weld metal sample or a complete weld zone made from the intended service material, and you must replicate the welding process, welding operating parameters, and operating conditions as closely as possible (including the base material conditions, geometry, and dimensions). You must also apply restraint. As a result, direct weldability tests are commonly referred to as actual welding tests in the industry once they have been completed.

The effect of welding parameters on the final output can be extrapolated by evaluating welding parameters on a sample after conducting indirect weldability tests on the sample. When this is done, the weld heat cycle is typically recreated in order to provide a simulated weld zone with the least amount of microstructure possible. These tests are often referred to as "simulated testing" in the industry because of this.

Weldability testing is a straightforward, practical, and, in most situations, cost-effective way of determining the impact of the welding process on actual weldments' quality, features, and performance. This information must be instantly applicable to a production weld, as well as sensitive to the impacts of welding conditions, with adequate reproducibility and ease of use. Weldability tests must also have these features.

A wide range of tests have been created to investigate and analyse the weldability of common metals and alloys. For the most part, these tests are used to determine the weldability of specific alloys, grades, or temperatures of the raw materials. As a result, the geometrical and physical characteristics of the specimen, as well as the welding conditions (process, parameters, technique, and so on) remain constant, leaving the base material as the only variable that is determined by the welding process. If this is not possible, these tests can be used to determine appropriate base materials (including fillers) and welding circumstances that will provide acceptable outcomes in the test and, ideally, in real-world applications once they have been completed. Weldability tests are used in the fabrication industry to determine the cracking susceptibility of a welded connection. It is common practise to classify them according on the type of cracking they induce. As a result, in certain quarters, fabrication weldability tests are referred to as crack susceptibility testing, which is a more accurate term. Because of this, fracture susceptibility tests are classified according to the zone in which they are conducted: fusion zone crack susceptibility tests, partially melted zone crack susceptibility tests, and heat-affected zone crack susceptibility tests. Fusion zone crack susceptibility tests are the most common.

Crack susceptibility tests, such as hot-cracking or super solidus crack susceptibility tests, are performed on materials to determine whether they are susceptible to cracking during solidification in the fusion zone or partially melted zone. In order to compare one base material to another, a variety of tests are carried out, some of which are completely qualitative, while others are semi-quantitative to quantitative, allowing for evaluation based on some quantifiable attribute, such as the amount of strain present in the base material under consideration.

The suitable tests for determining the crack susceptibility of various materials welded using a variety of procedures are summarised in the following Table 1.

Table 1. List of Weldability tests

TEST	Applicable material	Applicable Process	Purpose
Finger (hot cracking)	High-alloy steels,super alloys	GMAW	Effect transverse cracks
Houldcroft (hot cracking)	Al and steels	GTAW	Effect range of restraint
Battelle(hot cracking)	Plain-C,low-alloy,high speed steels	GMAW	Semi-quantative, restraint
Lehigh restraint(hot cracking)	Steels	Metal arc	Quantative effect strain
Varestraint (hot cracking)	Low and high alloy steels	GTAW	Quantative effect strain
Murex(hot cracking)	Steels	Metal arc	Evaluate filler metals
Circular groove/ segmented groove	Steels	Metal arc	FZ/HAZ hot or cold cracking
U.S.Navy circular patch	Steels	Metal arc	Hot and cold cracking

The 7xxx series alloys can be divided into two categories based on weldability, as illustrated in the table below. Al-Zn-Mg and Al-Zn-Mg-Cu are the most common alloys.

Heat cracking is more difficult to occur in Al-Zn-Mg-Cu Alloys like 7005, which is why they perform better in joints. It has been found that alloys with a high percentage of AlZnMgCu, such as 7075, perform better in joints. Alloys like Al-ZnMg (Al-ZnMg) normally have a higher cracking sensitivity due to the magnesium presence. This alloy group is easy to weld when using high magnesium filler alloys like 5356, as long as there is enough magnesium present to keep the weld from breaking. It is not suggested to employ filler alloys based on silicon, such as 4043, because the additional Si injected by the filler alloy can result in an undesirable accumulation of brittle Mg2Si particles in the weld. Alloys like 7075, which contain Al, Zn, Mg, and Cu, have a small quantity of Cu added in trace proportions. These minuscule levels of Cu, along with the Mg and Cu, help to boost fracture sensitivity by expanding the coherence range. Solidification stress is likely to cause breaking at grain boundaries, resulting in a material environment favourable to stress corrosion cracking in the future. The enhanced hot cracking sensitivity produced by widening the coherence range is not limited to welding more vulnerable base alloys like 2024 or 7075, but occurs in all welding circumstances. Using different base alloys (which are often easy to weld together) or an unsuitable filler alloy can greatly increase a weld joint's crack sensitivity. For example, you could join a 2xxx series base alloy with a 5xxx series base alloy by welding the two together, or you could combine a 2xxx series base alloy with a 5xxx series filler alloy by joining the two together. To increase crack sensitivity, mix high concentrations of Cu and Mg together. This increases crack sensitivity while also expanding the coherence range.

C. Solidification Cracking Phenomenon

An extremely low alloy ductility temperature results in the hot crack during solidification, which is when the fracture occurs. Solidification cracking occurs when thermal tensile strains from internal contraction and external displacement exceed the minimum tolerated strain required to start cracking. This temperature range is where cracking begins. Weak ductility combined with thermal strain during solidification results in brittleness.

The elements that contribute to hot cracking can be broadly categorised into the following:

- Mechanical factors
- Thermal factors
- Metallurgical factors

External factors such as thermal (heat input, cooling rate) and mechanical (restraint intensity) forces have an effect on the strain distribution surrounding the weld. Inherent factors are metallurgical properties of an alloy that determine its inherent cracking susceptibility. The following are the inherent factors: Aluminum alloys display a significant sensitivity to solidification cracking due to their high solidification shrinkage coefficient (near 6 percent of its volume). Crack susceptibility vs alloying content is also extremely dependent on the alloy composition curve, which is very dependent on the alloy composition curve.

1) Mechanical Factors

Cracking occurs as a result of neighbouring grains being subjected to mechanical forces during the solidification process. Thermal contraction, solidification shrinkage, or a combination of the two can generate this type of stress. Aluminum alloys have a high coefficient of thermal expansion and a low solidification shrinkage, making them ideal for aeronautical applications. As a result, solidification cracking can be rather severe in certain aluminium alloys, especially those with a wide range of solidification temperatures. The degree to which the work piece is constrained is another mechanical factor that affects solidification cracking. Even when the same joint design and material are used, the more constraint placed on the work piece, the more likely solidification crackling will occur.

2) Thermal Factors

For example, solidification rate, arc heat input, and thermal strain generated by solidification are all factors that might affect the performance of a weldment. The trailing arc approach is used to alleviate cracks caused by the solidification rate. Vibration is utilised to regulate the pace of cooling of the weldment in order to avoid solidification cracking.

3) Metallurgical Factors

One of the metallurgical elements that has been demonstrated to influence weld metals' susceptibility to cracking during solidification is the volume and distribution of liquid during the terminal stage of solidification. All of these features are impacted by the composition of the weld metal, either directly or indirectly.

D. Alloy Composition

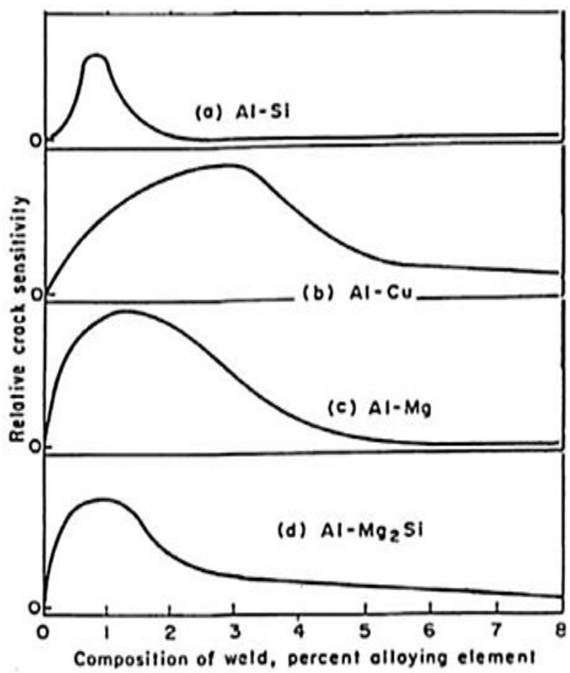


Fig1.Solidification cracking susceptibility versus alloying content.

Metallurgical concerns are taken into account in this project endeavour to avoid the occurrence of solidification cracking. This may include altering the base metal's chemical composition. By adjusting the magnesium and silicon content, which affect weldability and castability, using the fracture sensitivity graph in Fig 1 and the ASM registered 7xxx series alloy, the magnesium and silicon content can be modified.

Zinc is the predominant alloying element in AA7075, whereas magnesium, copper, silicon, and other elements also contribute to the alloying composition. After examining the effects of magnesium and silicon on crack sensitivity, it was discovered that the crack sensitivity of Al-Mg is increased when the magnesium content is between 0.5 and 3% of weight, whereas the crack sensitivity of Al-Si is increased when the silicon content is around 1% of weight. Due to their location at the peak of the fracture sensitivity graph, the magnesium and silicon contents of AA7075 are altered, resulting in three various types of compositions, as shown in Table 2.

Table 2. Modified Chemical composition of Aluminum alloy

<table>
<tr><th rowspan="2">Specimen</th><th colspan="5">Composition by (wt. %)</th></tr>
<tr><th>Mg</th><th>Si</th><th>Zn</th><th>Cu</th><th>Al</th></tr>
<tr><td>1</td><td>4.5</td><td>0.9</td><td rowspan="4">5.5</td><td rowspan="4">2</td><td rowspan="4">Remaining</td></tr>
<tr><td>2</td><td>4.5</td><td>1.5</td></tr>
<tr><td>3</td><td>2.9</td><td>1.5</td></tr>
<tr><td>4</td><td>2.9</td><td>0.9</td></tr>
</table>

IV EXPERIMENTAL WORK

A. Stir Castng

Stir casting is a liquid state alloy manufacturing technique in which two separate metals are mixed mechanically to generate a new alloy. After determining the composition, the alloys are made by the stir casting process. Alloying elements are added in the proportions indicated by the weight percentages in Table 3 a - d. The raw material was loaded into a graphite crucible and then heated to 800 degrees Celsius in a top-loaded resistance furnace. Fig. 2 illustrates the configuration of a stir casting machine. The alloying components copper, zinc, silicon, and magnesium are added in the following order: copper, zinc, silicon, and magnesium. Solid raw materials are introduced. Using the plunger rod process, the magnesium is wrapped in aluminium foil, resulting in a high magnesium recovery rate (95 percent) in the alloy. Due to the fact that no atmospheric air (oxygen) came into contact with the heated magnesium during this method, there was no loss of magnesium as oxide or emergence of any flashes during the alloy formation process. From top to bottom, the aluminium foil holding magnesium particles is placed into the melt. When immersed in the super-heated Al-melt, the aluminium foil melts in less than 30 seconds when the magnesium particles are released rapidly and spread almost uniformly throughout the melt as a result of the melt's stirring effect. When used in the production process, the four-blade stirrer depicted in Figure 3 was created to ensure that particles were distributed uniformly throughout the matrix material throughout the process. Because high temperatures might cause a reaction between stainless steel and aluminium alloys, the stainless steel stirrer blade was coated with zirconia before to use in order to avoid this reaction. Throughout the activity, the stirring speed of 450 revolutions per minute was maintained. Allow the mixture to harden in a steel die that has been preheated to 300°C. As illustrated in Figure 4, the molten metal was poured manually into the mould. The casted sample is shown in Figure 5 after it has been cast into the die, which contains a 100*100*10 mm cavity.

Table 3 a. Raw Material for Sample 1

Alloying elements	Zn	Mg	Si	Cu	Al
Wt (%)	5.5	4.5	0.9	2	87.1
Wt (g)	82	67.16	13.43	29.8	1300

Table 3 b. Raw Material for Sample 2

Alloying elements	Zn	Mg	Si	Cu	Al
Wt(%)	5.5	4.5	1.5	2	87.5
Wt(g)	82.65	67.63	22.54	30.05	1300

Table 3 c. Raw Material for Sample 3

Alloying elements	Zn	Mg	Si	Cu	Al
Wt(%)	5.5	2.9	0.9	2	88.7
Wt(g)	80.60	42.50	13.19	29.31	1300

Table 3 d. Raw Material for Sample 4

Alloying elements	Zn	Mg	Si	Cu	Al
Wt(%)	5.5	2.9	1.5	2	88.1
Wt(g)	81.15	42.79	22.13	29.51	1300

Fig 2. Machine setup of stir casting

Fig 3. Mixing of Alloying Element

Fig 4. Manual Pouring

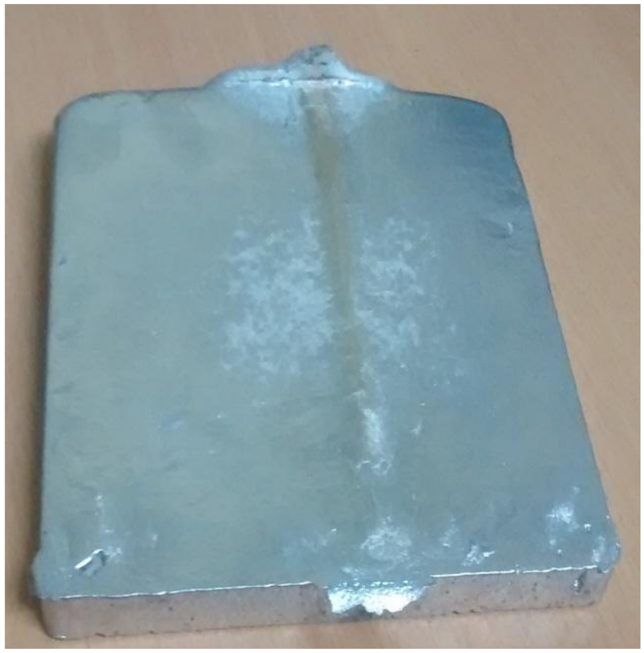


Fig 5. Casted Sample

B. Specimen Preparation

The Houldcroft test specimens were machined to be three millimetres thick, 45 millimetres broad, and 76 millimetres long with a slot thickness of three millimetres. The distance between the slots can range between 8mm and 5mm, depending on the application.

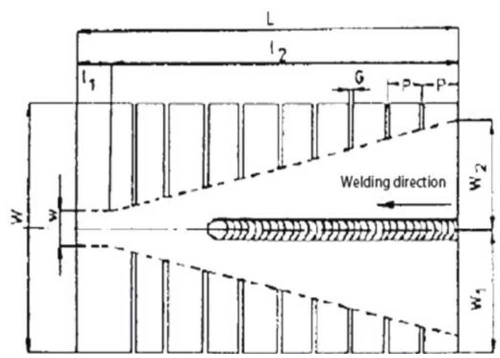


Fig 6. Schematic of Houldcroft cracks susceptibility test

Fig 6 shows the schematic representation on specimen fabricated for hot cracking test as per the dimensions mentioned in the Table 4.

Table 4 Dimensions of Houldcroft test

Weldability method	W	W1	W2	W	L	l1	l2	p	G	t
GTAW	45	22.3	19	6.4	76	6	70	8.5	1	3

The GTAW approach was employed to finish the penetration of the manufactured specimen, which was made with a 3.2mm diameter electrode and shielded with argon. The length of the slots is shortest at the beginning of the weld, the stiffness is greatest, and the fracture will develop. Due to the increased length of the slots, the sample's stiffness decreases, and the fracture formed at the beginning gradually disappears completely. FIGURE 7 depicts the specimen that was produced for the Houldcroft test.

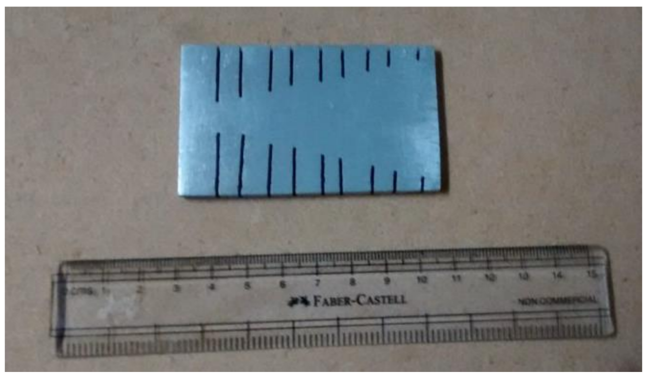


Fig 7 Fabricated sample used for Houldcroft test

C. Houldcroft Crack Susceptibility Test

Both the GMAW and GTAW procedures are capable of causing solidification cracking in thin aluminium materials (2–3 mm), and the Houldcroft weldability test (Fishbone test) is an efficient tool for examining this phenomena. As a result, it is the test that is most frequently used for this purpose. Due to the fact that the foundation is made of aluminium with a thickness of 3mm, the Houldcroft test is used in this case. The specimen is perpendicular to the weld and features several parallel grooves of varied sizes. These slots diminish the stiffness of the sample. When the Houldcroft test specimens were developed, they were used to determine the cracking tendency of sheet materials exposed to GTAW without filler material under high restriction. The length of the produced crack is measured, and this information can be used to quantify the fracture sensitivity of the material and to compare its susceptibility to solidification cracking.

D. Test Procedure

1) *Welding Process*

GTAW is chosen over GMAW and FSW processes because of the following reasons:

- It was discovered that GMAW-fabricated joints had lower strength values than GTAW-fabricated joints, with a roughly 28 percent gain in strength value.

- When compared to the HAZ and BM regions, the weld metal (WM) zone has a lower hardness. When comparing the GTAW and GMAW processes, a significant degree of hardness is achieved.
- The FSW process alters the microstructure of the HAZ, resulting in its softening and poor corrosion resistance.
- By contrast, the GTAW process does not alter the microstructure and the composition remains stable.

2) Welding Setup

The UA TIG BP315 AC/DC source was used for GTAW welding, as seen in Fig. 8. The Houldcroft test for GTAW is suited for samples with a thickness of 3-4 mm and a thickness of 3-4 mm. The welding parameters must be selected in such a way that the weld penetrates entirely from the start, resulting in the appearance of a fracture at the weld start. To identify the conditions for complete penetration and fracture occurrence, tests on specific samples were done. Table 5 summarises the findings of these testing. The diameter of the tungsten electrode was chosen to be 3.2 mm. Ar with a purity of 4.6 and a flow rate of 17 litres per minute is used as the shielding gas. All samples were run in the same setup. The oxide layer was manually removed before to welding with a stainless brush, and the samples were degreased to prepare them for welding. A welding fixture was utilised to clamp the workpieces during the welding process to prevent distortion. The weld begins on the shorter slotted side and progresses to the longer slotted side.

Table 5 GTAW Welding Parameters

Parameter	Value
Base current	90A
Peak current	230A
Voltage	16V
Electrode diameter	3.2 mm
Torch gas	Argon
Flow rate	17l/min
Polarity	AC

Fig 8. Welding machine

3) Weldability Measurement

The fracture that happens during welding is measured with a ruler and the resulting data is used to determine the material's weldability. A weld's weldability is determined by its fracture sensitivity. Crack sensitivity is defined as the relationship between the length of the crack and the overall length of the weld. It is feasible to determine the specimen's crack sensitivity by using the formula presented in equation (1)

$$CASE\ SENSITIVITY = \left(\frac{l_1}{l_0}\right) \times 100\ (\%) \qquad (1)$$

A = crack sensitivity [%],
l_1 = crack length [mm],
l_0 = weld length [mm]

The total length of the weld in Houldcroft test is 76mm

All samples are fused using the identical welding settings, and the fracture sensitivity of each sample is determined and compared to that of 7075 to determine which sample has the least crack sensitivity.

V RESULTS AND DISCUSSION

A. Houldcroft Test Results

Houldcroft tests were performed on the samples using the TIG welding procedure, and the crack lengths detected in each sample were measured and are listed in Table 6. As can be seen from the table, AlMg4.5,Si1.5,Zn5.5 exhibits the shortest crack length.

Table 6 Crack length of the welded samples

Sample No	Composition	l_1	l_2	l_3
1	AA7075	60	55	57
2	Al,Mg 4.5%, Si 1.5%, Zn 5.5%	38	36	39
3	Al,Mg 4.5%, Si 0.9%, Zn 5.5%	38	43	45
4	Al,Mg 2.9%, Si 1.5%, Zn 5.5%	46	45	61

B. Crack Sensitivity Ratio

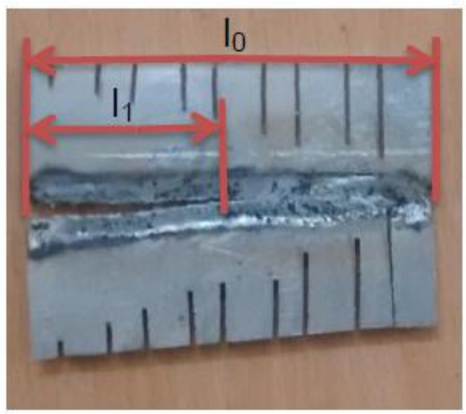


Fig 9. Welded Houldcroft sample

The crack sensitivity is calculated using the formula given in equation (2)

$$CASE\ SENSITIVITY = \left(\frac{l_1}{l_0}\right) \times 100\ (\%) \qquad (2)$$

l_1= crack length (mm),
l_0= weld length (mm) = 76 mm
The crack sensitivity ratio of each sample is calculated and listed in the Table 7.

The diameter of the tungsten electrode was chosen to be 3.2 mm. Ar with a purity of 4.6 and a flow rate of 17 litres per minute is used as the shielding gas. The filler wire was the sole exception, as it was used with the same setting in all of the samples. The oxide layer was manually removed before to welding with a stainless brush, and the samples were degreased to prepare them for welding. The welded Houldcroft samples of varied compositions have been welded together, as depicted in Fig.10 a-d.

Fig 10 a- sample no.1

Fig 10 b- sample no.2

Fig 10 c- sample no-3

Fig 10 d- sample no-4

Table 7 – Crack sensitivity

Crack sensitivity			
Sample No	A %	A %	A %
1	78.9	72.3	75
2	50	47.3	51.3
3	50	56.5	59.2
4	60.5	59.2	80.2

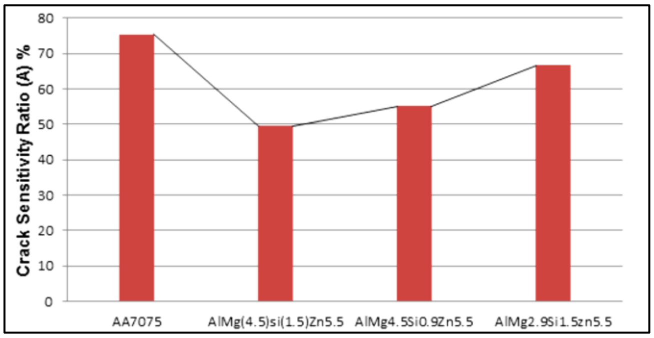


Fig. 11 Crack sensitivity ratio

The average crack sensitivity of each sample is determined by evaluating three specimens. As seen in the graph, the susceptibilities of the three alloys to solidification cracking vary significantly from those of AA7075. The alloy AA7075 has the highest crack sensitivity of 75.4 percent, while the alloy AlMg(4.5)Si(1.5)Zn(5.5) has the lowest crack sensitivity of 49.5 percent. According to this observation, the sample containing magnesium 4.5 percent and silicon 1.5 percent produced the best results of all the samples, as shown in Figure 11, and is less crack-sensitive than AA7075. When an alloy is exposed to a temperature range where the ductility is exceedingly low, a cracking reaction occurs during or immediately after solidification. Cracking can occur before, during, or right after solidification. Solidification cracking occurs when thermal tensile strains from internal contraction and external displacement exceed the minimum tolerated strain required to start cracking. This temperature range is where cracking begins.

As seen in Fig. 11, the presence of a high magnesium and silicon content in aluminium helps to prevent cracking from occurring. For this reason, due to the fact that magnesium has a higher solute content and a lower melting point than the parent metal, it allows for the formation of enough eutectic liquid to back fill tears during solidification [13].

According to the manufacturer, magnesium's ductility and strength increase by 0-6 percent as the temperature rises [15]. As a result, when exposed to brittle temperatures, the mushy zone's ductility rises, preventing the breaking. In the casting of aluminium alloys, increased eutectics with a low melting point are present, and these eutectics are dispersed in a continuous net shape along grain boundaries. Mechanical loads created during welding are dominated by thermal strains, which are caused by temperature variations surrounding and within the mushy zone. Rapid cooling after welding results in solidification shrinkage (due to phase shift) and thermal contraction of the solid skeleton, which are both undesirable. All of these pressures have the potential to cause liquid films to decohere, which in turn can result in the creation of cracks in the material. Even slight increases in the concentration of Si have been demonstrated to have a significant impact on the solidification process in laboratory experiments. Although the solidus temperature decreases from 577 to 509°C when the silicon concentration is increased from 0.50 to 1.40 weight percent, the interdimeric component increases from 2 to 14 weight percent when the silicon content is increased from 0.50 to 1.40 weight percent. Also documented is that raising the silicon concentration resulted in grain refinement and a reduction in solidification shrinkage during the solidification process, both of which are beneficial.

C. Mechanical Properties Test Result

1) Tensile Test

Magnesium salt with a content of [4,5]% AlMg. The tensile specimen was made to the ASTM E8M-04 standard using a Si[1.5]Zn[5.5] alloy base metal, as shown in Fig. 12. A universal testing machine (UTM) was used to conduct tensile tests in accordance with ASTM standards, and the results are given in Annexure I and Tables 8.1 and 8.2.

Fig. 12 Fabricated tensile test specimen.

When AlMg4.5Si1.5Zn5.5's tensile strength was compared to that of AA7075, it was determined that it has less strength since it was measured in the cast state rather than after forging, extruding, or rolling, as in mechanical working. While there will be some porosity and hot spots in the cast condition, these can be reduced by the application of mechanical and heat treatment procedures.

2) Hardness Test

For testing, a 100kg applied stress and a 1/16-inch diameter penetrator were used, along with a Rockwell hardness tester. Table 9 shows the average findings from the three B scale readings, and the report is included as Annexure ii. Three readings were taken on the B scale, with the average of those readings appearing in Table 9. We measured the weldment as well as the base metal. It was necessary to take hardness measurements at intervals four times the indenter's size across the whole welding region to avoid localised strain hardening effects at the indentation. These measurements were taken half the depth of the fusing zone. Weld bead hardness increased by 17.5 percent after the welding process as a result of exposure to high temperatures during the welding process. Mg2Si has a high hardness value because of the presence of magnesium and silicon in the Weld bead.

Table 8.1 - Tensile test result

S.no	Description of the sample	Gauge Size (mm)	C.S Area mm2	Yield Stress N/mm2
1	Al Mg 4.5 Si1.5Zn 5.5	10* 16	160	141.2

Table 8.2 – Tensile test result

S.no	Description of the sample	Ultimate Stress N/mm^2	Breaking Load N	Elongation mm	% Elongation
1	Al Mg 4.5 Si1.5 Zn 5.5	165	24000	34	6.25

Table 9 - Hardness Test Result

S.No	Description of sample	Rockwell hardness number "B" Scale	Vickers Hardness number
1	AlMg4.5Si1.5Zn5.5 (base metal)	39	76
2	AlMg4.5Si1.5Zn5.5 (weld metal)	47	83

D. Productivity

Productivity is defined in the manufacturing business as an average measure of a manufacturing process's efficiency. It is the ratio of output to inputs utilised in the manufacturing process, or output per unit of input used in the manufacturing process.

1) Stir Casting Productivity

According to the weight % and density value of the raw material, the total weight of the raw material was determined, and the results are displayed in Table 10.

Table.10 -Weightage of alloying elements

Alloying elements	Zn	Mg	Si	Cu	Al
Wt(%)	5.5	4.5	0.9	2	87.1
Wt(g)	82	67.16	13.43	29.8	1300

Weight of raw material =1492.39gms

The stir casted part was dimension of 100*100*10 was shown in Fig 13. The weight of the casted part is 825grams.

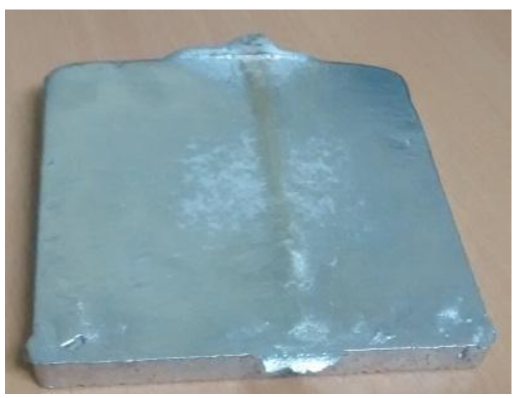


Fig 13. Casted Part

Yield or Productivity = 825/ 1492.39 = 55.28%

Losses have been discovered as a result of slag formation during melting, the reactivity of alloying elements with their environment, and the vaporisation of components like as magnesium.

2) Machining Productivity

Houldcroft specimens were machined to a thickness of three millimetres, a breadth of four millimetres, and a length of seven millimetres, with a slot width of one millimetre. The distance between the slots can range between 8mm and 5mm, depending on the application. The machined specimen weighed 605 grams, which is quite a bit of weight.

Productivity = 605/1492.39 = 40.53%

E. Spectro Analysis:

It is a quantitative technique that evaluates the elemental composition of the pieces by measuring their surface sensitivity. The result of the spectro analysis is shown in the Table 11 and Table 12.

Table 11 - Spectro analysis of sample 1

Element	Wt %
Al	89.29
Si	0.054
Fe	0.291
Cu	1.528
Mn	0.044
Mg	2.564
Cr	0.233
Ni	0.075
Zn	5.821
Sn	0
Ti	0.051
Pb	0.014
Ca	0.003
Be	0.001
Sr	0.002
Zr	0.008
Bi	0.031
Ga	0

Table 12 - Spectro analysis of sample 2

Elements	Wt %
Al	85.92
Si	0.996
Fe	0.335
Cu	2.022
Mn	0.018
Mg	4.752
Cr	0.012

Ni	0
Zn	5.892
Sn	0.012
Ti	0.005
Pb	0.012
Ca	0.007
Be	0.001
Sr	0.002
Zr	0.004
Bi	0.001
Ga	0.009

VI. CONCLUSION

In the process of reducing the hot cracking susceptibility of AA7075, the various factors which cause the hot cracking were studied and the metallurgical factors were selected to reduce the hot cracking. The effects of various alloying elements present in the AA7075 were studied. The various hot cracking tests were analyzed and the Houldcroft test was chosen for the experimentation work. The magnesium and silicon contents were chosen to vary based on their effects on hot cracking. The composition of new alloy was fixed based on the crack sensitivity graph. From the experimental work done it is evident that with the increase in magnesium and silicon content the hot cracking susceptibility gets reduced. The tensile and hardness test for AlMg4.5Si1.5Zn5.5 were performed and the value of the results obtained was less than the standard values of 7075. This is because the tensile and hardness test were performed in the as cast material. From the result it is inferred that if the magnesium and silicon content were increased in parent metal the crack sensitivity reduced and it can be welded autogenously using GTAW.

Following the findings of this investigation, there are areas in which further research would be beneficial for the development of high strength 7xxx aluminum alloy using GTAW:

The experiment have been conducted for a single set of welding parameters, it can be welded with different set of parameters and an optimization can be done to obtain better results in the weldment. Robotic welding setup can be used to reduce the variability in the testing conditions.

- In this work the specimens have been used in as cast condition, it can be metal worked and heat treated to enhance its mechanical properties.
- Number of samples used for experimentation can be increased to improve the accuracy of test results.
- Microstructure studies can be done to understand about the weld and heat affected zone.

REFERENCES

1. N. Coniglio and C.E. Cross (2008) “Weld Parameter and Minor Element Effects on Solidification Crack Initiation in Aluminum” journal of Hot Cracking Phenomena in Welds II, pp.277-310.

2. Sindo kou. 2002. Welding metallurgy,Volume 1, pp.263-293
3. Tolga Dursun, Costas Soutis, (2014): "Recent developments in advanced aircraft aluminium alloys" journal of Materials and Design, vol-56, pp.862–871.
4. Wei Zhou,"Problems in Welding of High Strength Aluminium Alloys" Singapore Welding Society Newsletter, September 1999, pp.1-6.
5. P. Vijaya Kumar a, G. Madhusudhan Reddy b, K. Srinivasa Rao,(2015):" Microstructure, mechanical and corrosion behavior of high strength AA7075 aluminium alloy friction stir welds e Effect of post weld heat treatment", journal of defence technology,pp 1-8.
6. Hakem. Maamar, R. Rabah otmani, T. Fahssi, n. Debbache,d. Allou, (2008): "Heat treatment and welding effects on mechanical Properties and microstructure evolution of 2024 and 7075 aluminium alloys" Materials Letters 41, pp.1-7.
7. C.E. Cross and N. Coniglio (2008)" Weld Solidification Cracking: Critical Conditions for Crack Initiation and Growth" journal of Hot Cracking Phenomena in Welds II, pp. 39-58.
8. Niel,F. Deschaux, C. Bordreuil, and G. Fras, (2013): "Hot-crack test for aluminium alloys welds using TIG process" HAL Id: hal-00807866.
9. Sivashanmugam. M, Jothi Shanmugam.C, Kumar. T, Sathishkumar.M,(2010): "Investigation of Microstructure and Mechanical Properties of GTAW and GMAW Joints on AA7075 Aluminum Alloy" IEEE, p p 241-246.
10. M. Temmar, M. Hadji, T. Sahraoui, (2011):"Effect of post-weld aging treatment on mechanical properties of Tungsten Inert Gas welded low thickness 7075 aluminium alloy joints" journal of Materials and Design, Elsevier vol-32, pp.3532-3536.
11. N.Nafsin, H. M. M. A. Rashed, (2013): "Effects of Copper and Magnesium on Microstructure and Hardness of Al-Cu-Mg Alloys", International Journal of Engineering and Advanced Technology, Volume-2, Issue-5, pp.533-536.
12. R. S. Rana, Rajesh Purohit, and S Das, (2012): "reviews on the influence of alloying elements on the microstructure and mechanical properties of aluminum alloys and aluminum alloy composite" International Journal of Scientific and Research Publications, Volume 2, Issue 6.
13. Rajneesh Kumar Verma, Lucky Agrawal and D. S. Awana, (2013): "Effect of Variation of Silicon and Copper Contents in Aluminium-Silicon-Copper Alloy", International Journal on Emerging Technologies, volume-4, issue-1, pp.149-156.
14. H.Nasr el-Din, S.F.Moustafa, A.N.Abdel-Azim and A.Ismail, (1992): "The determination of Aluminum-Magnesium Alloys" Journal of Metallurgical Science And Technology, Volume-10, pp.16-20.
15. B.P. Samal, A.K. Misra, S.C. Panigrahi, S.C. Mishra, (2013): "Plunger Technique: A new Approach to Stir Casting AMMC Preparation", Journal of materials and metallurgical Engineering, vol 3, issue 2, pp. 26-32.
16. L. Kolarik, K. Kovanda, M. Valova, P. Vondrous, J. Dunovsky (2011): "weldability test of precipitation hardenable aluminium alloy en aw 6082 t6", MM science Journal, pp. 242- 247.
17. N. Coniglio, C. E. Cross, T. Michael, and M. Lammers (2008):" Defining a Critical Weld Dilution to Avoid Solidification Cracking in Aluminum" Welding research journal, Volume 87, pp.237-247.