A Technical Review on Solidification Cracking Behaviour and Susceptibility of Aluminum Alloy Weld

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Trends in Mechanical Engineering & Technology
ISSN: 2231-1793 (Online), ISSN: 2347-9965 (Print)
Volume 8, Issue 2
www.stmjournals.com

A Technical Review on Solidification Cracking Behaviour and Susceptibility of Aluminum Alloy Weld

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Abstract

The paper deals with the physical, chemical properties along with important aluminum applications. Various defects are generated while welding of aluminum alloys one of the severe defects is cracks. Solidification and liquation cracks are generated at various zones of metals. Different mechanical and metallurgical factors affecting the solidification cracking. A variety of weldability tests like Varestraint test, Transvarestraint test, The Cast Pin Tear testHot Ductility test, Strain-To-Fracture test, Reheat Cracking test, Houldcroft (Fishbone) test appliesto investigate the susceptibility of cracking.

Keywords: *Cracking susceptibility, solidification cracking, weldability tests*

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INTRODUCTION

Aluminumand its Application

The one of richest element available in the earth crustis aluminum having 8% wt. which is second after ferrous alloy like steel between inexpensively significant metal. Some other nonferrous elements like copper, tin, lead were used for many years. Aluminum was identified by Sir Humphrey Davy (Britain) in 1808 [1].

Aluminum (Al) is low-density metal used in many industries like automobile, transportation, aerospace, civil constructions, packaging, storage, bridges *etc*. Aluminum is higher corrosive resistant metal. Some alloying elements are added like silicon, copper, zinc, magnesium, manganese to improve its properties. Al & Al-alloys have wide use because of many technological developments in it that provide quality &productivity (Figure 1). Especially welding technology is recognized to be vital in storage and automobile industries [2]. The enormous challenge for engineers and researchers are to welding Al metals. As a matter of fact, many intricacyis connected with the type of welding methods are oxide films, thermal conductivity, the coefficient of thermal expansion, solidification shrinkage, the solubility of hydrogen, and distinct gases [3].

Designation of Aluminum alloys

Aluminum alloys are designated by Mathers *at el*. [4]. This is shown below in Table 1.

Table 1: *Principle Alloying Elements.*

Sr. No	Alloy Series	Principle alloyingElement
1	1XXX	99.00% minimum Al
2	2XXX	Copper
3	3XXX	Manganese
4	4XXX	Silicon
5	5XXX	Magnesium
6	6XXX	Magnesium & Silicon
7	7XXX	Zinc
8	8XXX	Other elements

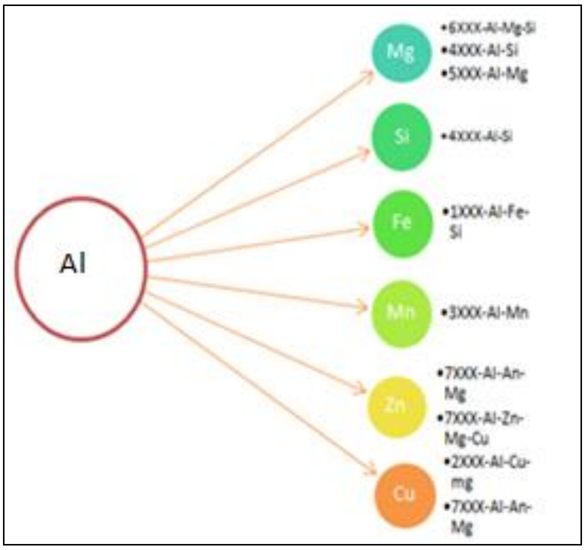


Fig. 1: *Classification of Wrought Al Alloy Series.*

Properties of Al Alloys

Physical properties of Aluminum (Al) alloy are given in table 2.

Table 2: *Physical Properties.*

Sr no	Property	Value
1	Atomic Number	13
2	Atomic Weight (g/mol)	26.98
3	Valency	3
4	Crystal Structure	FCC
5	Melting Point (°C)	660.2
6	Boiling Point (°C)	2480
7	Mean Specific Heat (0-100°C) (cal/g.°C)	0.219
8	Thermal Conductivity (0-100°C) (cal/cms. °C)	0.57

Chemical Composition of Al Alloys

The chemical composition of AA 6XXX is tabulated in below table 3.

Table 3: *Chemical Composition of AA 6XXX.*

Alloy	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	other
AA 6XXX	0.8-1.2	0.4-0.8	0.7	0.15-0.40	0.25	0.15	0.15	0.04-0.35	balanced

Mechanical Properties of Aluminum Alloy [6]

The mechanical properties like yield strength, ultimate tensile strength etc. are given in table 4.

Table 4: *Mechanical Properties of AA 6XXX.*

Type of Material	Yield Strength (MPA)	Ultimate Tensile Strength	Elongation	Hardness
AA 6XXX	302	34	18	105

ALUMINUM WELD ZONES

Analysis of welded joints reveals different regions of microstructures (Figure 2). It contains different regions like fusion zone, partially melted zone, heat affected zone *etc*. Melting and solidification of base metal, filler metal or electrode areknown as fusion zone. Base metal and melted metal interface is known as partially melted zone and base metal associated with heat by welding process is known as heat affected zone (HAZ). Outside region of HAZ is unaffected base metal. Many metals are possessing cubic crystal lattice. All metals have the general phenomenon of solidification process. In several metals, solidification behavior is exceptionally responsive to the composition *e.g.* the solidification behavior can be change to austenite (FCC) from ferrite (BCC) to few sheets of steel by adding little amount of carbon and nitrogen. In fusionzone, the small amount of sulfur to the steels can encourage relentless solidification cracking. Cracking can be avoided to the welded of Al alloys by using filler metal having greater than 6% of Si.

TYPES OF CRACKS

In Al alloys, many cracking mechanismshas been identified. According to temperature range, they are classified [7]. They are classified as follow (Figure 3 and Figure 4).

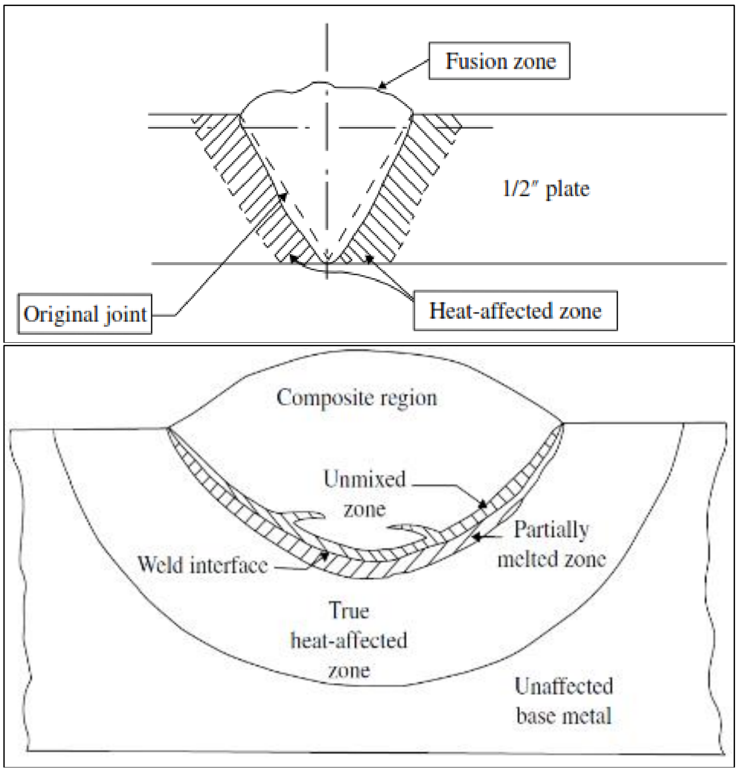


Fig. 2: *Fusion weld regions.*

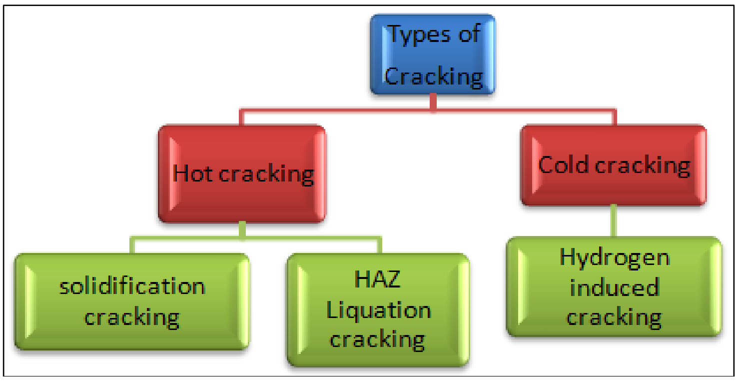


Fig. 3: *Types of cracking.*

Different cracks are generated different zones [7].

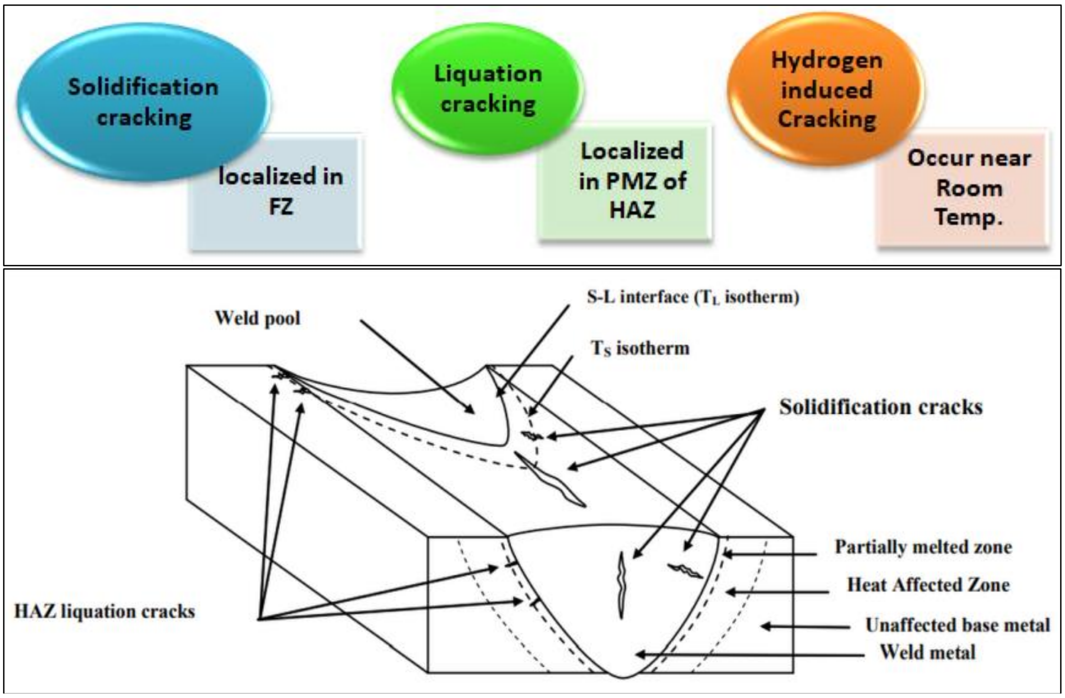


Fig. 4: *Cracks location in Aluminum welding.*

The solidification structure of weld metal is as shown in Figure 5.

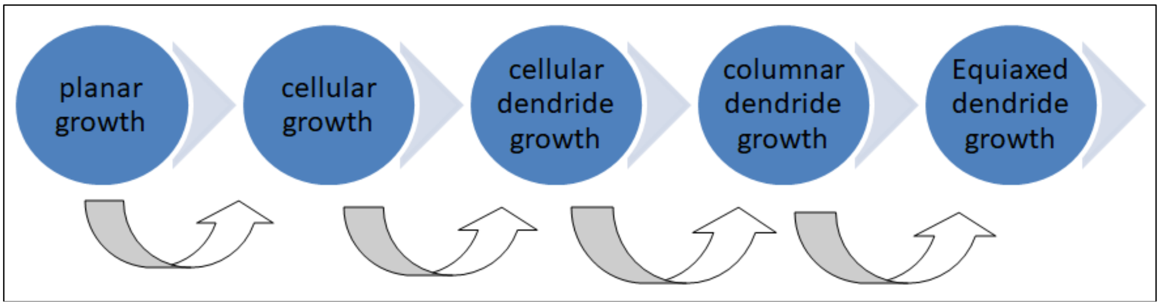


Fig. 5: *Solidification structure.*

SOLIDIFICATION CRACK GENERATION THEORY

Four major stages of solidification cracking [8]. At the 1st stage, initial dendrite generation, where the solid phase is isolated, and the liquid is uninterrupted, solid and liquid is capable of relative movement, and no cracks are generated (Figure 6 and Figure 7).

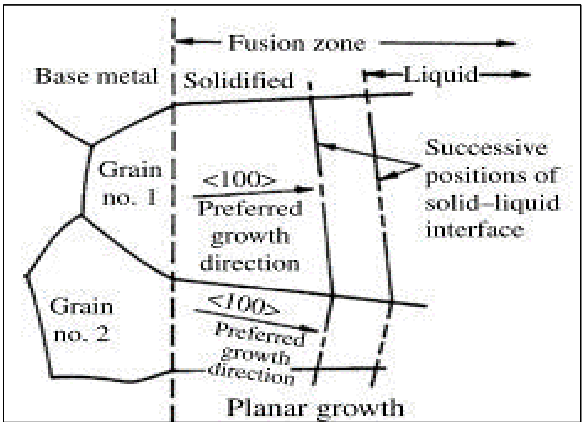
The 2nd stage includes dendrite interlocked, solid, liquid are uninterrupted but the only liquid is capable of relative movement and can flow freely among interlocking dendrites. In the 2nd stage, if strain rate is higher grains are pulled apart; the cracks are refilled and healed by the interconnecting cooling.

The 3rd stage is of growth of grain boundary, the crystals of solid are in an advantage of growth, and free route of liquid is restricted by a semi-continuous network of solids.

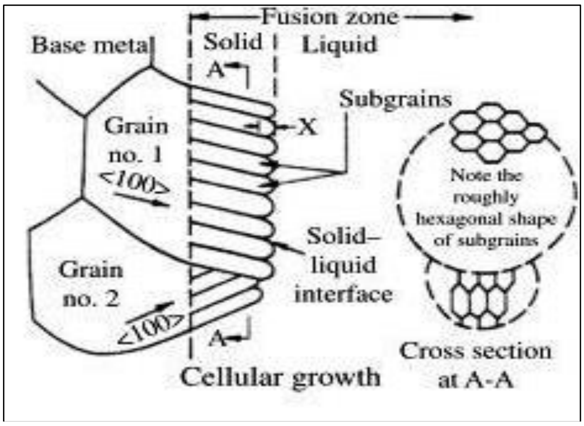
This is recognized as the critical solidification range. If the value of accommodated strains goes higher, no healing of cracks is feasible.

4th stage is full solidification, no cracks generated due to solidification of remaining liquids.

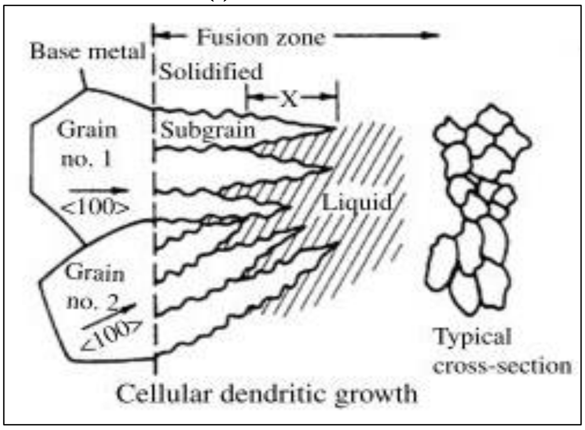
The mode of solidification cracking is explained by Figure 6.



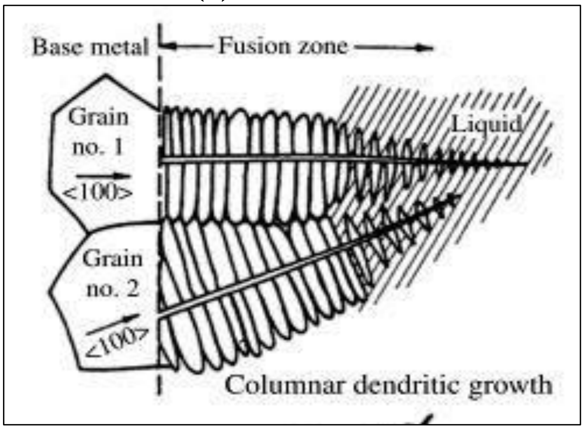
(i) Planar Growth



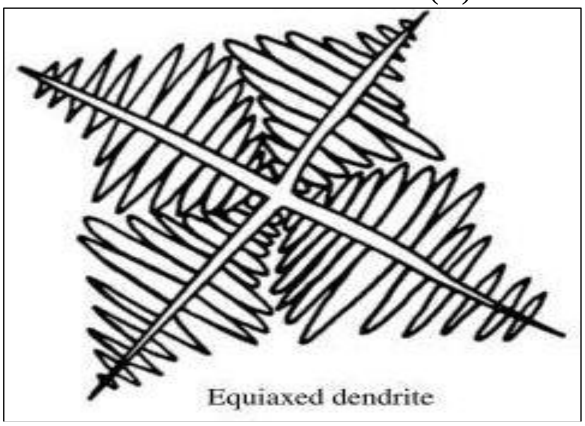
(ii) Cellular Growth



(iii) Cellular Dendritic Growth



(iv) Columnar Dendritic Growth



(v) Equiaxed Dendrite

***Fig. 6:** Solidification modes in fusion welding [9].*

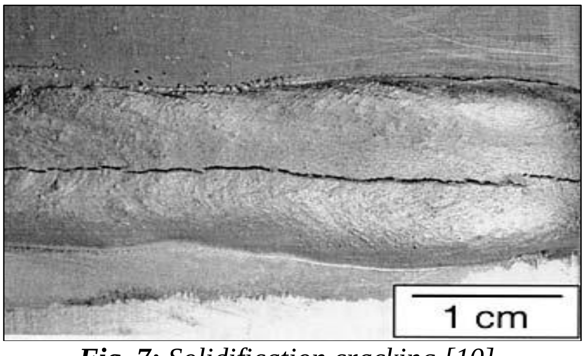


***Fig. 7:** Solidification cracking [10].*

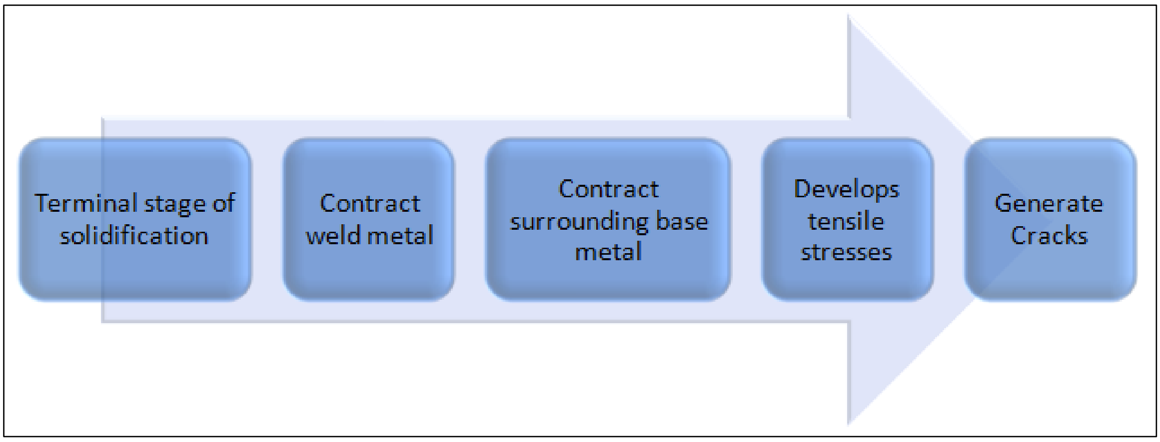


Fig. 8: *Solidification crack generation [10].*

Table 5: *ISO standards for Weldability Tests [9].*

ISO standard	Test type	Test technique
17641-2	Hot cracking, self-restraint	T-joint Weld metal tensile Longitudinal bend
17641-2	Hot cracking, externally loaded	Hot tensile Varestraint Flat tensile (PVR)
17642-2	Cold cracking, self-restraint	Controlled thermal severity (CTS) Tekken (Y-groove) Lehigh (U-groove)
17642-3	Cold cracking, externally loaded	Implant

The mechanism of how the solidification cracking generates are as shown in Figure 8.

METHODS OF IDENTIFICATION OF WELDABILITY

Weldability testing is usually used to evaluate the fabricability of metals by various welding processes and to find out the service performance of welded construction. There are many weldability tests have been used available but although there are hundreds of weldability tests that have been used to evaluate material performance, some of them have been standardized [9].

Many of the weldability tests that have been developed over the years are specific to certain types of weld cracking.

Several weldability tests have been developed in many years, some of them are specifically for types of weld cracking. For instance variant test was developed to evaluate solidification and liquation cracking susceptibility. Some of them arestandardized.ISO 17641 provides a method for hot cracking test and ISO 17642 provides a method for the cold cracking test.

This standard contains the Varestraint and PVR tests for solidification cracking. In Table 5 list of different ISO standards for different weldability tests.

Types of Weldability Test Techniques

The different types of weldability tests are as categories in Figure 9.

ISSN: 2231-1793 (Online), ISSN: 2347-9965 (Print)

Different weldability tests are performed to evaluate the cracking susceptibility of weld joints [11].

1. The Varestraint Test
    a. Spot
    b. Longitudinal
    c. Transverse
2. Transvarestraint Test
3. The Cast Pin Tear Test
4. The Hot Ductility Test
5. The Strain-To-Fracture Test
6. Reheat Cracking Test
7. Houldcroft (Fishbone) Test

Houldcroft (Fishbone) Test

The Houldcroft (fishbone) weldability test is most extensively used test and appropriate for scheming of solidification cracking of thin metals welded by different fusion welding process. In this test, the special specimen has to be prepared. This is shown in Figure 10. The specimen having several slots of different lengths that cut at right angle to the weld. These slots decrease the rigidity of the specimen. The fusion weld is done on the specimen. The length of the slot is minimal at the direction of welding progression. Minimum length slots provide higher rigidity and possibility of crack generation. By decreasing the length of slots decreases the inflexibility of the samples that will cease to end of cracks at some point. Crack length is measured and useful for identifying cracking susceptibility of weld specimen. The specifications of weldability test specimen specification are as below (Table 6).

Table 6: *Weldability test specimen specification.*

W	W_1	W_2	W	l_1	l_2	L	P	G	t
44.6	22.3	19	6	6	70	76	8	1	2

Then the full penetration weld is done. At the weld beginning the length of slots is minimal, rigidity maximal and the crack will occur. With the increase of the length of the slot, the rigidity of the sample decreases and the crack created at the beginning will cease to exist at some point.

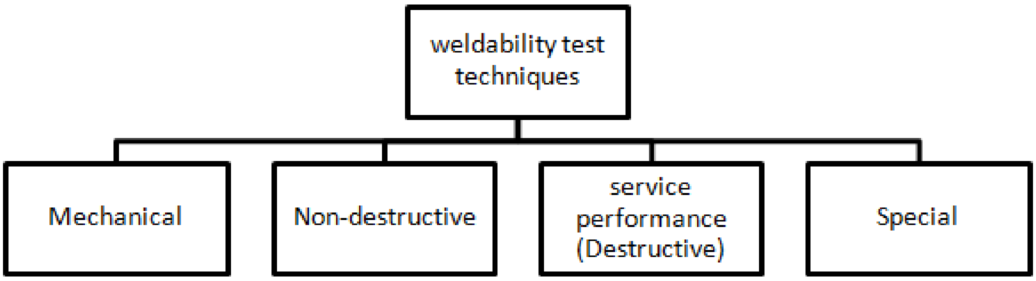


Fig. 9: *Weldability tests.*

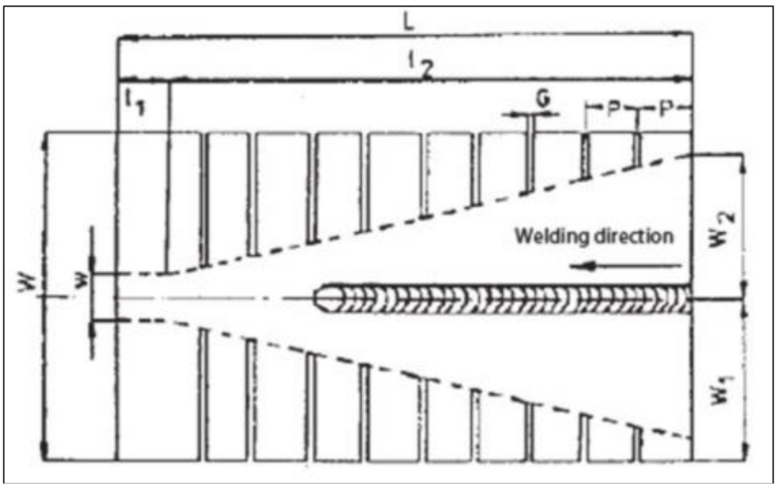


Fig. 10: *Houldcroft weldability test specimen[12].*

CONCLUSION

Aluminum alloys are more susceptible to solidification cracking. Many mechanical and metallurgical factors are affecting these cracks. Proper welding method and proper selection of electrode or filler metal are important to avoid cracking. The paper also tells about the theory of solidification cracks generation. Many weldability examinations are used to identify the susceptibility of cracking like Varestraint test, Transvarestraint test, the pin cast tear test, hot ductility test, strain-to-fracture test, reheat cracking test, Houldcroft (fishbone) test.

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Cite this Article

Pratik T. Kikani, Dr. Hemantkumar R. Thakkar. A Technical Review on Solidification Cracking Behaviour and Susceptibility of Aluminum Alloy Weld. *Trends in Mechanical Engineering & Technology*. 2018; 8(2): 77–84p.

