INFLUENCE OF THE WELD METAL CHEMICAL COMPOSITION ON THE SOLIDIFICATION CRACKING SUSCEPTIBILITY OF AA6056-T4 ALLOY






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ABSTRACT

The present study is one of the first steps towards the clear scientific understanding of the influence of the chemical composition of the weld metal on its susceptibility to the solidification cracking. It focuses on the experimental investigation of the influence of the silicon content in the weld metal by the laser beam welding of the aluminium alloy AA6056-T4. The blind seams have been produced on the so called fan-shape samples of AA6056-T4, varying only the filler wire supply rate. The dependence of centreline crack length on weld composition has been studied. It is shown, that the relatively small additions of the silicon to the weld metal lead to the sufficient increase of the cracking resistance. This positive effect is explained considering the particularities of the solidification cracking mechanism on the microscopic scale.

IIW-Thesaurus keywords: *Aluminium alloys; Light metals; Weld metal; Solidification cracking; Cracking; Defects; Hot cracking; Practical investigations; Silicon; Filler materials; Composition; Laser welding; Photon beam welding; Radiation welding.*

1 INTRODUCTION

Solidification cracking is one of the most frequent forms of weld defect which is observed during manufacturing. The cracking susceptibility is influenced by the wide range of process parameters such as welding speed, source power, clamping conditions, etc.

One of the most widely used methods for suppression of solidification cracking is the altering of the chemical composition of weld metal. The strong dependence of the cracking susceptibility upon the alloy composition has been clearly demonstrated already at the end of the 40-s in the pioneer works of Singer *et al.* [1-3] and Pumphrey *et al.* [4]. The positive influence of the silicon content in the aluminium alloys AA6XXX on the solidification cracking susceptibility has been shown in the works of Eskin *et al.* [5] and Cicala *et al.* [6]. However, the mechanism of influence of the weld metal chemical composition on the solidification cracking remains unclear up to the present day. This study is one of the first steps towards clear scientific understanding of the influence of the chemical composition of the weld metal on its susceptibility to the solidification cracking.

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2 EXPERIMENTAL PROCEDURE

The experiments described below focus on the investigation of the influence of the different silicon content in the weld metal on the susceptibility to the solidification cracking. The weld seams were produced on the so called fan-shaped samples [7]. This special geometry of the sample allows to generate and to stop the solidification crack during the welding process (Figure 1). The weld seam starts at the narrow edge of the sample and ends at the wider one. The initiation of the solidification crack occurs just after the start of the welding process at the narrow front edge of the sample due to the displacement of the surrounding base material outward from the weld centreline. This displacement is the mechanical response of the “fan”-geometry on the uneven temperature distribution, which is generated in the sample by the welding heat source. After initiation, the solidification crack propagates further following the motion of the weld pool. At the beginning of the welding process the relatively high value of the outwards displacement encourage the crack propagation. As the weld pool approaches to the wider edge of the sample, the value of the outwards displacement decreases due to the increase of the local stiffness of the base material. This poses difficulties for the further crack propagation. By the quite long samples the crack propagation is usually stopped somewhere within the sample. Every so often, especially by the relatively short sample length, the increase of the local stiffness of the base metal is not enough to stop the crack propagation and the crack reaches the wider sample edge together with the weld pool [Figure 2 a)]. In this case, the crack is not stopped due to the mechanical conditions, i.e. it would propagate further, if the sample were longer. In order to provide the local stiffness, which would always be high enough to stop the crack propagation within the sample, the standard experimental procedure was slightly modified by use of the restraints from both sides of the sample as shown in Figure 1 and Figure 2 b).

It should be emphasized, that the outwards displacement of the base material, i.e. the “driving force” for the crack propagation, depends predominantly on the geometry of the sample and on the heat input. It cannot be sufficiently affected by the weld metal chemical composition. The crack propagates until it is stopped due to the correspondent local stiffness. By the constant sample geometry and welding parameters, the difference in the chemical composition of the weld metal results in the different lengths of the solidification crack. It is apparent that the longer crack indicates the higher cracking susceptibility of the weld metal.

The aluminium alloy AA6056 with relatively low silicon content was used as a base material. The change of

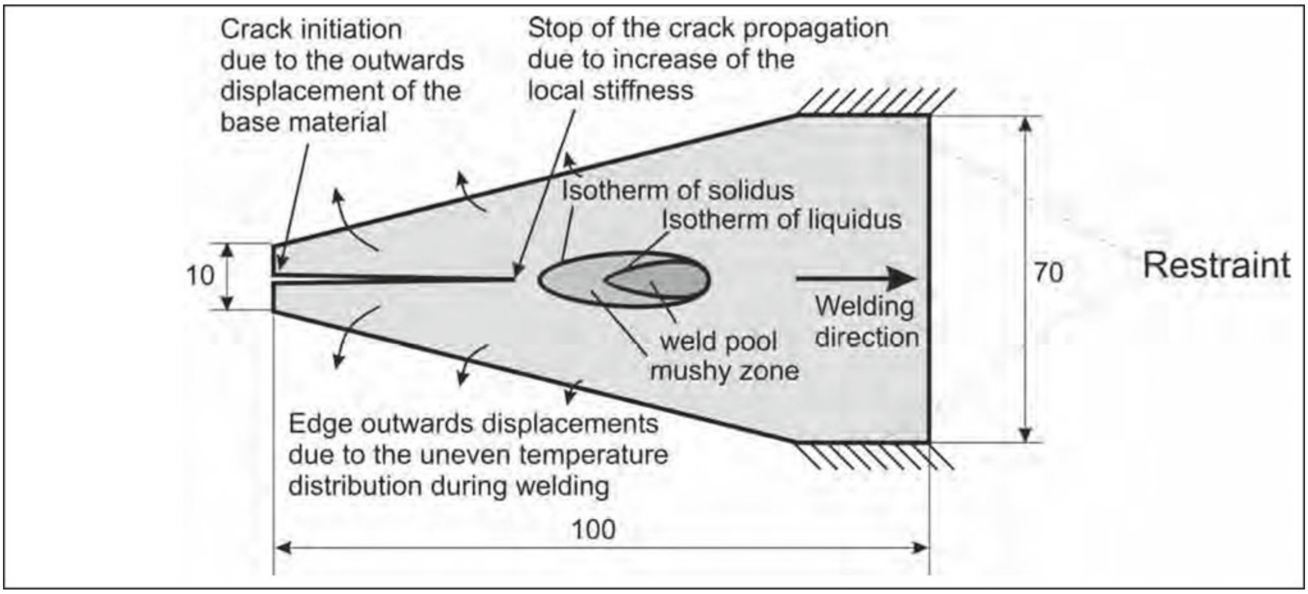
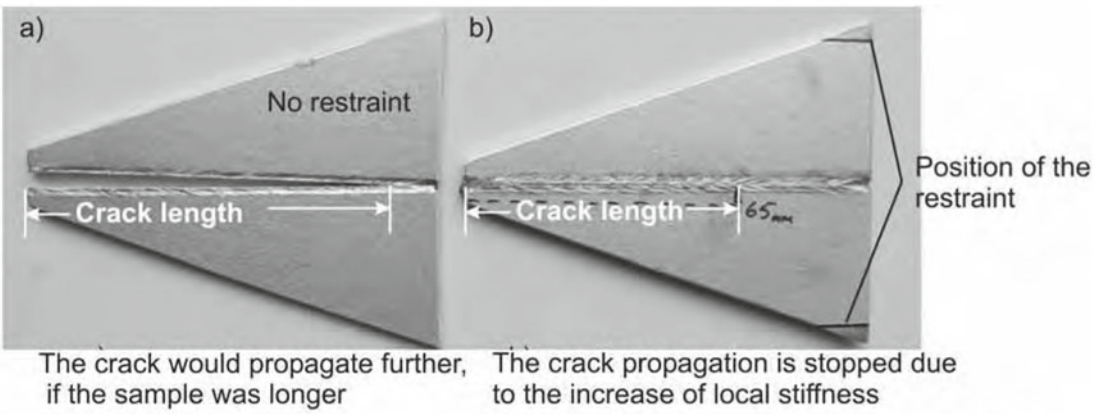


Figure 1 – Schematic representation of the experiments with the fan-shaped samples



The crack would propagate further, if the sample was longer

The crack propagation is stopped due to the increase of local stiffness

a) In the not restrained fan-shaped sample **b) In the restrained fan-shaped sample**

Figure 2 – The centreline solidification crack

the chemical composition of the weld metal was obtained by addition of the filler material with relative high silicon content under variable speeds of the filler wire supply. The chemical compositions of base material and filler wire are given in Table 1.

The thickness of the fan-shaped samples was 3 mm, the diameter of the filler wire was 1.2 mm and the welding speed was 2.7 m/min for all experiments. The laser beam power was slightly increased with the increasing supply of filler wire in order to compensate the higher heat lost. Parameters of the welding process are given in Table 2.

3 RESULTS AND DISCUSSION

The distribution of the silicon in the weld seams was measured by the scanning electron microscope using the energy dispersive X-ray analysis (EDX). The average concentration of silicon in the weld metal was also estimated using the following mass balance equations:

$$Si = 12 \cdot x + 0{,}8 \cdot (1 - x)\ ;\ x = \frac{\pi \cdot d_f^2}{4} \cdot \upsilon_f / d \cdot W \cdot \upsilon_{weld}$$

where

x is the fraction of the filler material in the weld metal;
d is the thickness of the sample, mm;
W is the width of the weld, mm;
υ_{weld} is the welding speed, mm/s;
d_f is the diameter of the filler material wire, mm;
υ_f is the filler material supply speed, mm/s.

Table 1 – Chemical composition of base material and filler wire

Mass %	Si	Cu	Mg	Mn	Zn	Al
Base metal	0.8	1.0	0.75	0.43	0.15	Rest
Filler material	12	–	–	–	–	Rest

Table 2 – Parameters of the welding process, silicon content and crack length

n/n	Laser power W	Filler wire supply speed m/min	Si-content, mass %	Crack length mm	Average crack length mm
1	3 200	2	1.6	66	67
2	3 200	2		65	
3	3 200	2		69	
4	3 200	2		68	
5	3 300	4	2.0	54	51.8
6	3 300	4		49.5	
7	3 300	4		51.5	
8	3 300	4		52	
9	3 400	6	2.8	32.5	33.9
10	3 400	6		36	
11	3 400	6		33.5	
12	3 400	6		33.5	
13	3 500	8	3.5	30	29.9
14	3 500	8		28.5	
15	3 500	8		31	
16	3 500	8		28	

The silicon concentrations in welds obtained by both methods are in a very good agreement, Figure 3.

The length of the centreline solidification cracks was measured using the optical microscope. The calculated silicon content in the weld metal and the correspondent length of the centreline solidification cracks are presented in Table 2.

First of all it should be pointed out that the relatively small variations of the silicon concentrations in the weld metal (from 1.6 % up to 3.5 %) lead to the sufficient decrease of the crack length (from 67 mm to approx. 30 mm) which is shown in Figure 3. As seen, the higher silicon content in the weld metal leads to the smaller crack length, i.e. the silicon improves the resistance of the weld metal to the solidification cracking.

As already mentioned in the previous section, the higher silicon content in the weld metal cannot exert some sufficient effect on the outwards displacement of the base material. The origins of the positive effect of the silicon on the resistance to the solidification cracking can be better explained, if we focus on the changes of the microstructure of the weld metal which can be produced by relatively small increase of the silicon concentration.

The microstructural nature of the solidification cracking was discussed in details in our previous work [8]. The mechanism of the solidification cracking on the macro- and microscopic scale is illustrated in Figure 4. The crack critical region is the intergranular film of the residual liquid in the mushy zone behind the weld pool. This liquid film accumulates the tensile strain transmitted from solid regions by the dendrites of the primary solidified phase. The initiation of the solidification crack (tearing of the intergranular liquid film) occurs when the accumulated displacement exceeds some critical value.

Even a cursory examination of the possible effects of the silicon concentration on the microstructure of the mushy zone reveals that the most significant changes can be expected by the distribution of the solid and liquid fractions. The estimation of the liquid fraction distribution can be carried out by use of the modern thermo-dynamic software tools [9]. The results of calculations of the liq-

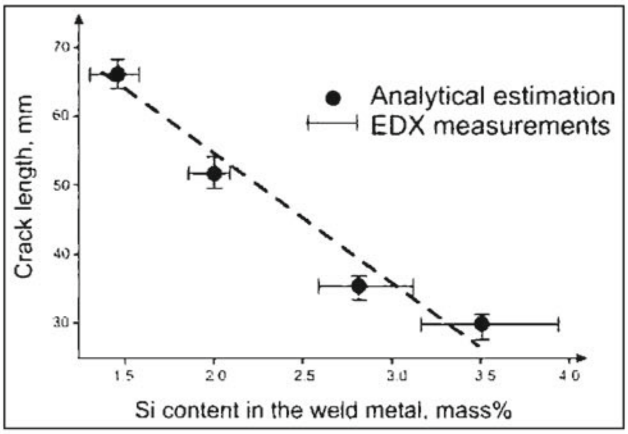
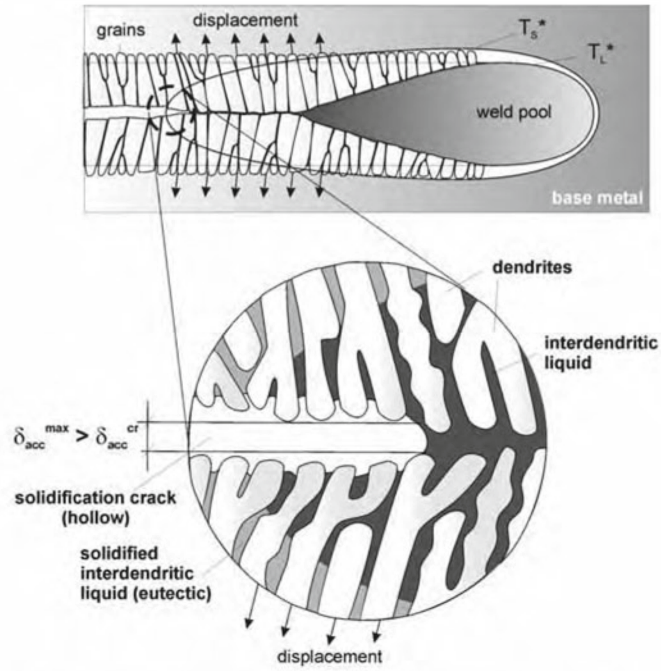
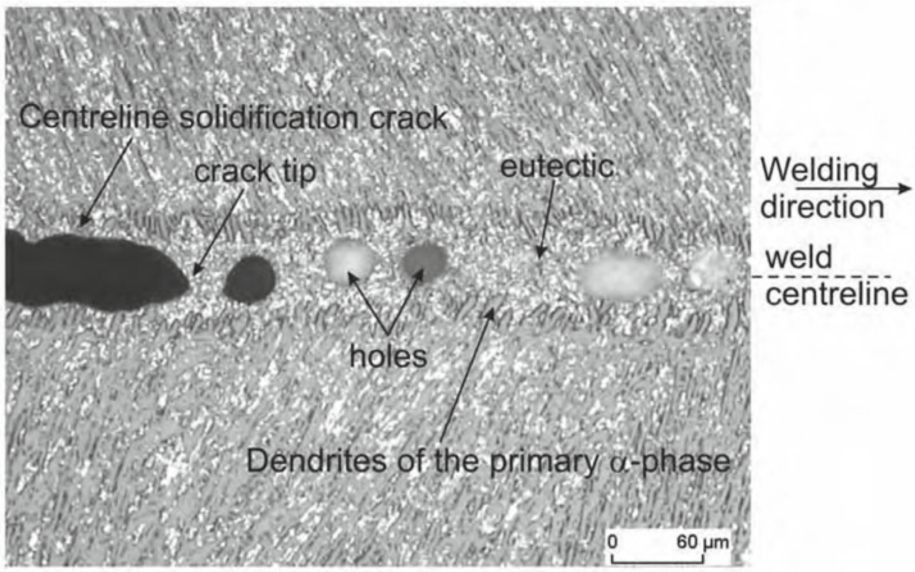


Figure 3 – The average length of the centreline solidification crack vs. the average silicon content in the weld metal



a) Schematic representation on the macro- and microscopic scale



b) Experimental micrograph of the "frozen" tip of the centreline solidification crack (top view of the weld, binary Al-4 %Si alloy)

Figure 4 – Microscopic nature of the solidification cracking mechanism

uid fraction as a function of the temperature for the different silicon contents in the weld metal are shown in Figure 5. The characteristic bending points on the curves of the liquid fraction correspond to the last stage of the solidification. At this stage, the mushy zone of the weld consists of the solid dendrites of the primary phase (α-dendrites in the case of the alloy AA6056) and the residual liquid. At the weld centreline, the α-dendrites grown from the opposite sides are separated by the film of the residual liquid phase (see Figure 4). These solid dendrites transmit the outward displacement into the residual liquid film. It is obvious that the film of the residual liquid with the larger thickness would better withstand the displacements leading to the tearing of this film.

On the other hand, the thickness of this film should correlate with the fraction of the liquid phase. As seen in Figure 5, the relatively small variations of the silicon content (from 1.6 % up to 3.5 %) lead to the sufficient increase of the residual liquid fraction (from approx. 10 % to 25 %). This fact helps us to reveal a justified explanation of the positive effect of the small additions of silicon on the solidification cracking resistance of the weld metal. Figure 6 represents the dependence of the average length of the centreline solidification crack on the silicon content recalculated in terms of the residual liquid fraction on the basis of the experimental dependence already shown in Figure 3. As seen, the grade of the decrease of the crack length is of the same order as

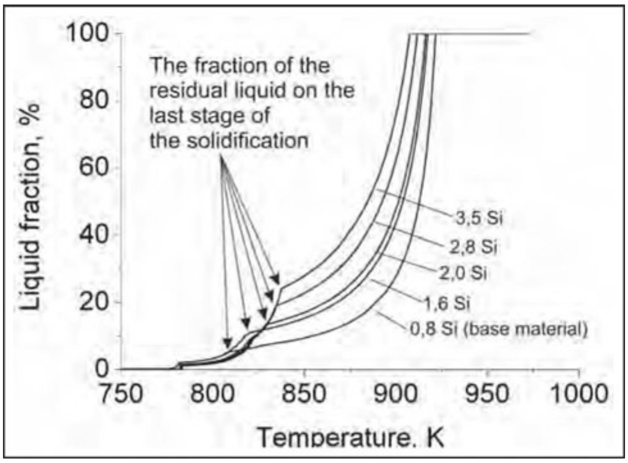


Figure 5 – Temperature dependence of liquid fraction for Al-alloys with different content of Si

the grade of the increase of the residual liquid fraction at the last stage of the solidification. Thus, the positive influence of the silicon can be explained in the following way: the small additions of the silicon lead to the sufficient increase of the liquid fraction, and, therefore, to the larger thickness of the film of the intergranular residual liquid. Due to the larger thickness, the film of the residual liquid can better withstand the outwards displacement and, therefore, it exhibits the better resistance to the solidification cracking.

4 CONCLUSION

The experimental investigation of the susceptibility of the weld metal to the solidification cracking as a function of its chemical composition have revealed that the small additions of a certain component (silicon in the case of welding of the aluminium alloy AA6056) can lead to the sufficient increase of the cracking resistance. The mechanism of this positive influence can be explained by the effects of the chemical composition on the microstructure of the weld metal, namely, on the value of the liquid fraction in the mushy zone at the last stage of the solidification. For the case of the alloy AA6056, it is shown, that the small additions of silicon (from 0.8 % to 2.7 %) to the weld metal will lead to the sufficient increase of the residual liquid fraction in the critical region of the mushy zone (from approx. 10 % to 25 %) This increase of the liquid fraction is of the same order as the experimentally observed solidification cracking susceptibility. It is supposed, that the higher fraction of the residual liquid causes the larger thickness of the intergranular liquid film and result in the better ability of the microstructure in the mushy zone to withstand the solidification cracking.

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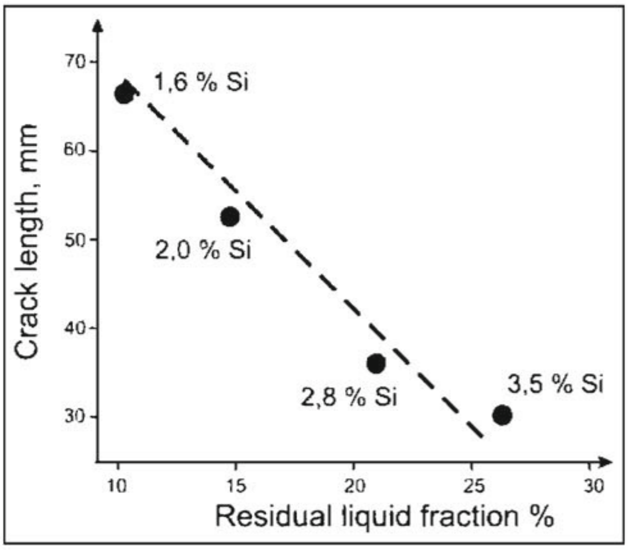

Figure 6 – The average length of the centreline solidification crack vs. the fraction of the residual liquid at the last stage of solidification

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