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## Laser Weldability of Different Al-Zn Alloys and its Improvement

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**Abstract.** Weld defects - such as porosity and hot cracking - occur especially during the laser beam welding of high-alloyed Al-Zn alloys. This significantly limits the application range of these promising high-strength alloys. In the present study the laser weldability of Al-Zn alloys was investigated regarding welding parameters and chemical composition of the alloys. In addition, the novel approach of the Helmholtz-Zentrum Geesthacht for overcoming the weldability problems was applied to the different Al-Zn alloys in order to assess its capability. It was shown that the laser weldability of Al-Zn alloys deteriorates with an increasing amount of Zn, Mg and Cu. The variation of laser welding parameters did not lead to any improvement of weldability. Only the use of a V foil as additional filler material resulted in promising welding results even for high-alloyed Al-Zn alloys.

### Introduction

Lightweight material concepts are needed to solve the controversy between public and private mobility and environmental conservation in terms of reduction of CO<sub>2</sub> emissions.

Heat-treatable Al-Zn alloys are promising candidates for the use as structural lightweight materials for automotive and aircraft applications. This is mainly due to their high strength-to-density ratio in comparison to conventionally employed Al alloys. Laser beam welding (LBW) is an efficient method for producing joints with a high weld quality and is established in the industry since many years. However, it is well known, that high-alloyed Al-Zn alloys are very hard to fusion weld - and thereby also to laser weld - due to the appearance of distinct weldability problems like porosity, hot cracks, weld metal expulsion and strength undermatching of the welds [1,2]. This inferior laser weldability significantly limits the application range of these high-strength alloys.

**Laser weldability.** Laser weldability is the ability of a material to be joined by LBW. This includes the absences of any considerable defects in the resulting weld - such as porosity and cracks. It is mainly influenced by the chemical composition as well as the resulting metallurgical and physical properties of the material. Welding parameters should play as far as possible only a subordinated role.

It has been pointed out by Mondolfo and Ma, that the total amount of Zn, Mg and Cu of an Al-Zn alloy is a feasible indicator for the resulting properties and especially for its weldability. Al-Zn alloys with a total amount above 9wt.% are expected to exhibit high strength, but also an inferior weldability [2,3].

One of the major problems of LBW Al-Zn alloys is the formation of porosity. In the work of Verhaeghe a distinction is drawn between gas-induced and keyhole-induced porosity [4]. Gas-induced porosity generally results from a limited amount of gas, which is dissolved in the weld metal. In this regard hydrogen is considered as the principle source of porosity in welded Al alloys due to the high solubility of hydrogen in liquid Al compared to solid Al. Hydrogen originates from base and filler materials mainly in form of an oxide layer and surface contaminations or it dissolved in the bulk material. The H<sub>2</sub> solubility is thereby influenced by the chemical composition of the Al alloy [4]. In contrast to that, keyhole-induced porosity results from instabilities of the keyhole during LBW in form of necking, swelling and collapsing of the keyhole. The reason for this is

mainly the non-uniform vaporization of volatile alloying elements - such as Zn and Mg - and the resulting differing vapour pressure. By this, large amounts of metal vapour, shielding or atmospheric gasses can be entrapped in the weld metal. For this reason the resulting pores are considered to be larger as in case of gas-induced porosity [4]. Furthermore the collapsing of the keyhole is often also accompanied by considerable weld metal expulsion.

Another problem during the LBW of Al-Zn alloys is hot cracking. It can occur in form of solidification cracking in the weld metal or in form of liquitation cracking in the heat affected zone (HAZ) - more precisely in the partially melted zone. Hot cracking can be explained by presence of low-melting grain boundary eutectics and sufficient critical stresses [5]. The solidification range is influenced by the chemical composition of the alloy. By the variation of welding parameters the heat input and hence the resulting stresses may be partly influenced.

The present study deals with the laser weldability of different Al-Zn alloys and its improvement. Therefore the influence of welding parameters and the chemical composition on the weldability of Al-Zn alloys was investigated. In addition, the novel approach - which includes the use of V foil additionally to a conventional filler wire - was applied to improve the laser weldability of these hard-to-weld alloys [6].

### Materials and experimental procedures

**Base and filler materials.** The base materials (BM) in this study were the commercial alloys AA7075, AA7050 and AA7034 and the pre-alloys PA734 and PA765. These Al-Zn alloys mainly differ in their Zn, Mg and Cu content. AA7034 and PA765 were only available as extruded profiles. All sheets were machined to a nominal thickness of 2mm either by milling or by spark erosion. As filler wire the Al-Mg alloy AA5087 with a diameter of 1.0mm was used, which is supposed to reduce the hot cracking susceptibility of the weld metal. As additional filler material - concerning the approach for improving the weldability - a V foil with a purity of 99.8% and a thickness of 40 $\mu$ m was used. The chemical compositions of the all alloys are shown in Table 1.

Table 1. Chemical compositions (wt.%) of the used Al alloys.

Alloy	Temper		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
PA734	T76	BM	0.03	0.04	2.1	-	1.6	-	6.8	0.02	Bal.
AA7075	T6	BM	0.4	0.5	2.0	0.3	2.9	0.28	6.1	0.2	Bal.
AA7050	T76	BM	0.12	0.15	2.6	0.1	2.6	0.4	6.7	0.06	Bal.
PA765	T79	BM	0.05	0.1	0.6	0.14	2.7	0.15	9.5	0.02	Bal.
AA7034	T6	BM	0.1	0.12	1.2	0.25	3.0	0.2	12.0	-	Bal.
AA5087	-	FM	0.25	0.4	0.05	1.1	5.2	0.25	0.15	-	Bal.

**Hydrogen measurement.** The initial H<sub>2</sub> content of the Al-Zn alloys was measured by a hydrogen analyser, Leco RH-402 - calibrated with H<sub>2</sub>. Therefore samples of the same size were extracted from each Al-Zn alloy. The preparation of the samples by grinding and cleaning with alcohol resembles the preparation for LBW. In this way, the influence of oxide layers and surface contaminations can be reduced to a minimum. All measurements were repeated three times to determine the average H<sub>2</sub> content.

**Laser beam welding.** The LBW of butt joints was performed using a 3-axial CNC machining centre which was connected to a 2.2kW Nd:YAG laser. The fibre had a diameter of 300 $\mu$ m and the laser optic had a focal length of 250mm. This resulted in a focussed beam diameter of approximately 370 $\mu$ m. The welding configurations differ for each of the three performed welding scenarios and are described in the following (see also Table 2).

At the beginning, a 'worst-case' scenario welding was performed. For this purpose no shielding gas and no filler material was employed. By keeping the LBW parameters for all Al-Zn alloys constant, it was possible to determine the influence of the chemical composition on weldability.

Next, a welding parameter study - only for AA7075 - was performed in order to determine the potential to optimize welding parameters, which may lead to a reduction of weld defects and hence to improved weld properties. Therefore, the following parameters were varied: laser power, focal position, welding speed and filler wire feed rate.

And finally, the novel approach was applied to perform an 'enhanced' scenario welding. By the use of a V foil additionally to the conventional filler wire the weldability shall be improved. The approach was applied to all Al-Zn alloys in order to validate its capability for different chemical compositions. The welding configuration for this scenario is shown in Fig. 1.

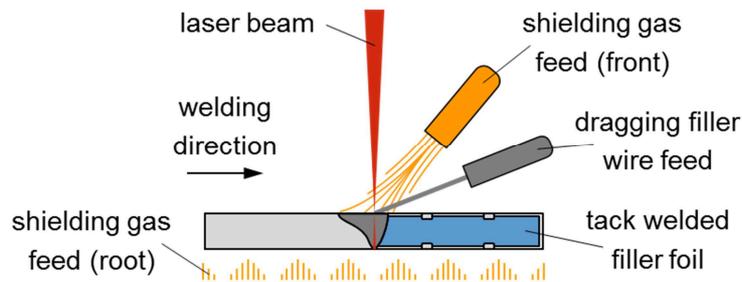


Fig. 1. LBW configuration used for the 'enhanced' welding scenario.

Table 2. LBW parameters used for the three scenarios.

Scenario	laser power [kW]	focal position [mm]	welding speed [m/min]	filler wire	filler wire feed rate [m/min]	shielding gas (front/root)	shielding gas flow rate [l/min]
'worst-case'	2.0	0	3.5	-	-	-	-
variation	1.2-2.0	(-2)-(+2)	2.5-5.5	AA5087	0-3.5	Ar/Ar	20/5
'enhanced'	2.0	0	3.5	AA5087	2.5	Ar/Ar	20/5

**Non-destructive testing.** Visual inspection was performed to record the outer appearance of the resulting welds. Moreover, X-ray inspection was performed to determine inner weld imperfections such as porosity and cracks.

**Destructive testing.** The microstructural features of the welds were investigated by optical microscopy. Vickers microhardness measurements were performed to determine the local mechanical properties of the welds.

## Results and discussion

**Hydrogen content.** In Fig. 2 the results of the hydrogen measurements for the used Al-Zn alloys are shown. It can be seen, that there is no clear dependency of the H<sub>2</sub> content on the amount of Zn, Mg and Cu which are the main alloying elements of Al-Zn alloys. Even for high-alloyed Al-Zn alloys the average H<sub>2</sub> content remains constant. In addition, the overall H<sub>2</sub> level is with approximately 1-2ppm very low. By this, it is possible to exclude in advance the H<sub>2</sub> content as the main cause for the weldability problems of the Al-Zn alloys.

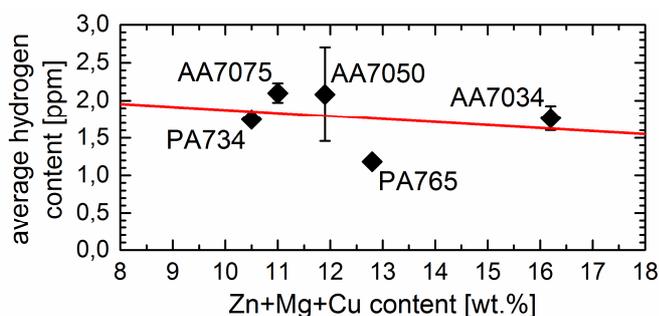


Fig. 2. Influence of the Zn+Mg+Cu content on the average H<sub>2</sub> content (with error bars) of the different Al-Zn alloys.

**Visual inspection.** The 'worst-case' welds showed that with increasing Zn+Mg+Cu content the laser weldability substantially deteriorates (see Fig. 3). It became apparent, that the proneness for spike formation, weld metal expulsion (spatter) and vaporisation increases. The brownish and

whitish deposits on the surface - especially on the root side - are originating from vaporisation of Zn and Mg during LBW. The worst weld quality was observed for AA7034.

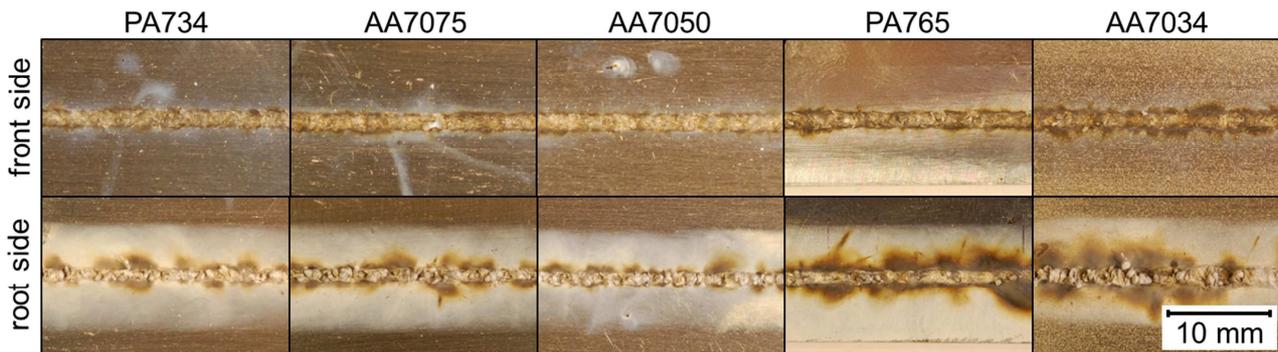


Fig. 3. Front and root side of the 'worst-case' welds.

By variation of the LBW parameters three different types of weld roots were identified, as shown in Fig. 4. In case of too low line energy - the ratio of laser power to welding speed - an incomplete penetration was observed. A further increase of the line energy led either to a spiky root for high welding speeds or to an excess of penetration for low welding speeds. The latter is also true for an increasing amount of fed Al-Mg wire. Defocussing of the laser beam in negative direction - into the specimen - even facilitated the formation of spikes. Spike formation was always connected with an increased weld metal expulsion.



Fig. 4. Typical appearances of the weld root: incomplete penetration (a), excess of penetration (b) and spike formation (c).

In contrast to the 'worst-case' welds, the 'enhanced' welds showed a uniform appearance for all Al-Zn alloys, as it can be seen in Fig. 5. In addition, spike formation and weld metal expulsion was eliminated.

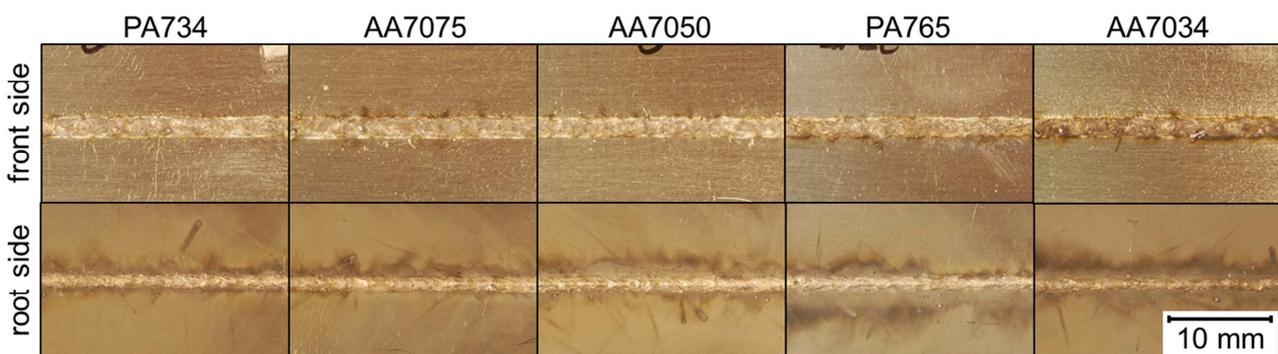


Fig. 5. Front and root side of the 'enhanced' welds.

**X-ray inspection.** From the radiographs of the 'worst-case' welds in Fig. 6 it can be seen, that all alloys show only a limited number of pores, but severe weld seam irregularities exist. This can be explained by the fact, that most of the weld metal is expelled - mainly at the root side - during LBW and by this fewer pores can be entrapped. In case of the 'enhanced' welds no severe porosity or weld seam irregularities are observed (see Fig. 6). A unique characteristic of AA7034 is the occurrence of macroscopic cracks - running perpendicular to the welding direction - for the 'worst-case' welding (as indicated in Fig.6).

The radiographs of the 'enhanced' welds in Fig. 6 show a regular weld seam appearance with very little residual porosity - which may originate from the use of an Al-Mg filler wire - and some

non-melted or non-dissolved parts of the V foil. The increased density of the weld seam can be explained by the higher density of V in comparison to Al.

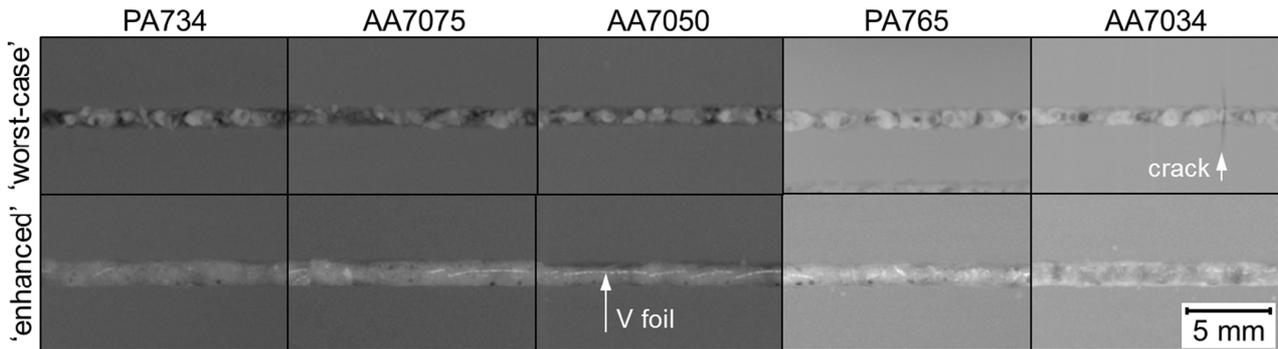


Fig. 6. Radiographs of the 'worst-case' and 'enhanced' welds.

Clear porosity was mainly observed for welds - of the parameter variation - with an incomplete penetration or an excess of penetration, whereupon the size of pores seems to be larger for the weld with excess of penetration, as shown in Fig. 7.

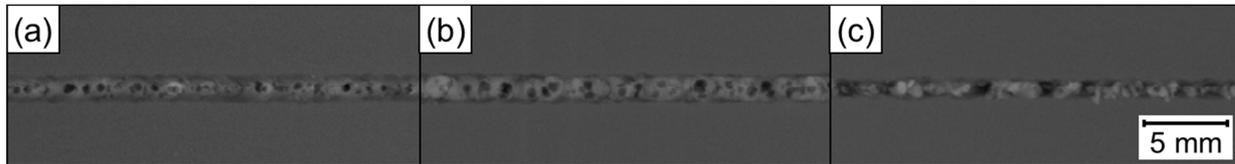


Fig. 7. Typical radiographs of welds with incomplete penetration (a), excess of penetration (b) and spike formation (c) (see also Fig.4).

**Microstructural properties.** The macrographs of the 'worst-case' welds showed a distinct undercut at the top and excess of penetration or spike formation at the root of the weld seam. In case of the AA7034 also severe microscopic cracks in the HAZ are present, which are supposed to be liquidation cracks.

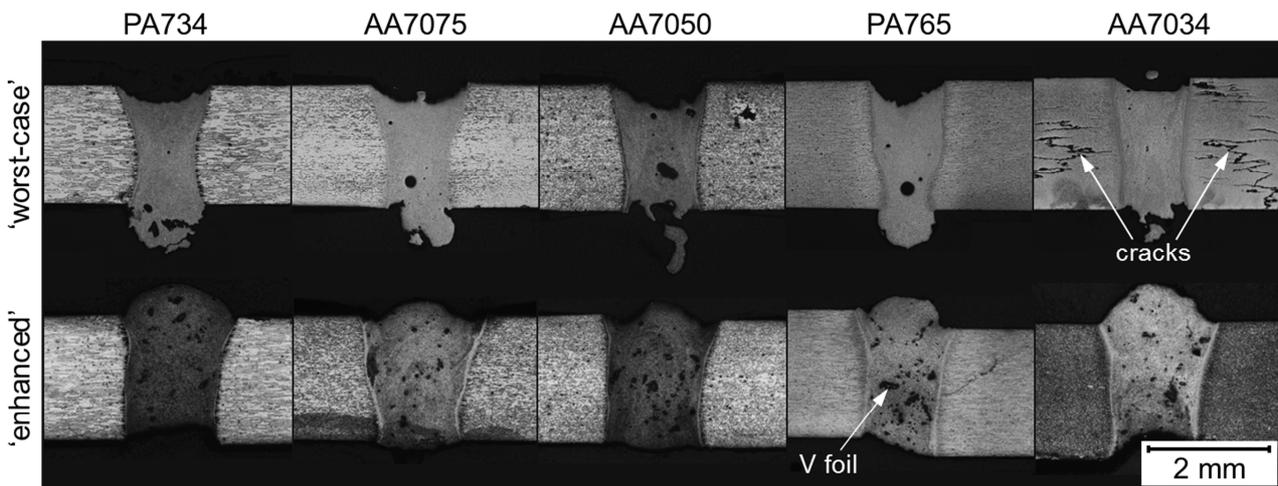


Fig. 8. Macrographs of the 'worst-case' and 'enhanced' welds.

Due to the use of filler material, the undercut at the top of the weld seam was eliminated, as shown in Fig. 8, whereas the root side shows no excess of penetration. Only in case of the AA7034 an undercut at the root side can be observed. In addition, the amount of pores was significantly reduced. But due to incomplete melting or dissolving of the V foil, tiny V-rich particles can be observed in the weld seam.

The effectiveness of the novel approach can be explained by changed thermophysical properties of the melt pool due to the use of V. Here, the main changes are: an improved pressure balance in the keyhole, an increased surface tension and viscosity as well as a reduced thermal diffusivity.

**Microhardness.** In Fig. 9a it becomes apparent, that with increasing Zn+Mg+Cu content the microhardness also increases. The weakening of the HAZ and weld zone (WZ) of the ‘enhanced’ welds due to welding is very low. It ranges from -5% to -24% compared to the BM. This can be explained by the low heat input during LBW and the adding of V, which has a very high initial hardness. The hardness peaks in the WZ of the ‘enhanced’ weld are caused by V-rich particles, whereas the hardness troughs in the HAZ of the ‘worst-case’ welds are caused by the presence of cracks, as it can be seen in Fig. 9b (see also Fig.8). The influence of V-rich particles on the mechanical properties - such as formability and fracture behaviour - is described in [7] and [8].

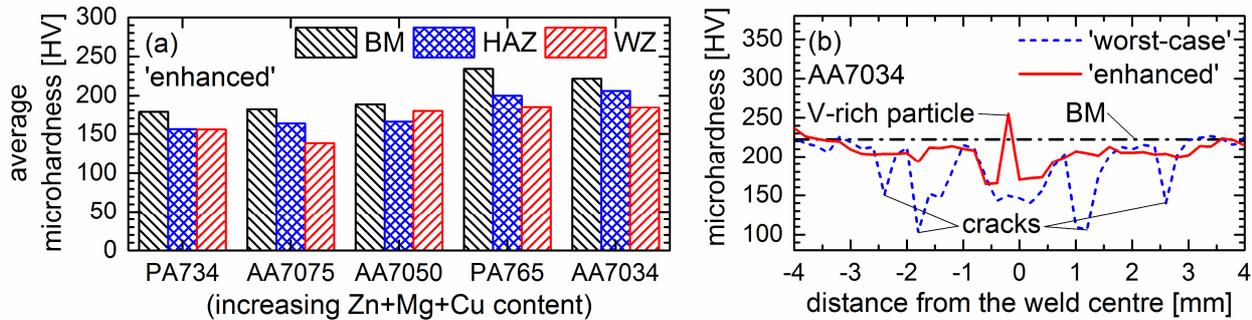


Fig. 9. Average microhardness of the ‘enhanced’ welds (a) and exemplary comparison of the microhardness of a ‘worst-case’ and an ‘enhanced’ weld of AA7034 (b).

## Summary

On the basis of the obtained results of this study the following conclusions can be drawn:

- (1) The laser weldability of high-alloyed Al-Zn alloys deteriorates with increasing amount of Zn+Cu+Mg. Owing to the low H<sub>2</sub> content of all base materials, the reason for the inferior weldability can be explained by keyhole instabilities due to vaporisation of the volatile elements Zn and Mg.
- (2) It is not possible to improve the laser weldability of Al-Zn alloys solely by variation of welding parameters - such as laser power, focal position, welding speed and filler wire feed rate.
- (3) An improvement of laser weldability can be achieved by the use of the novel approach. In particular, the weld seam appearance can be improved and the amount of porosity can be significantly reduced.

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