Journal of Manufacturing Processes 29 (2017) 272–280

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Research Paper

Mechanical properties of laser beam welded similar and dissimilar aluminum alloys

J. Enz [a,b,*], M. Kumar [c], S. Riekehr [a], V. Ventzke [a], N. Huber [a], N. Kashaev [a]

[a] Helmholtz-Zentrum Geesthacht, Institute of Materials Research, Materials Mechanics, Max-Planck-Straße 1, 21052 Geesthacht, Germany
[b] TuTech Innovation GmbH, Harburger Schloßstraße 6-12, 21079 Hamburg, Germany
[c] Light Metals Technologies Ranshofen, Austrian Institute of Technology, 5282 Ranshofen, Austria

ARTICLE INFO

Article history:
Received 17 February 2017
Received in revised form 10 July 2017
Accepted 27 July 2017

Keywords:
Al-Zn-Mg-Cu alloy
Al-Mg alloy
Laser beam welding
Dissimilar joint
Mechanical property
Sheet metal forming

ABSTRACT

Two approaches were used for laser beam welding of similar and dissimilar joints of AA7075 and AA5182 that aim to overcome the weldability problems of high-strength Al-Zn-Mg-Cu alloys. The first approach implies the use of vanadium foil as additional filler material, while the second implies the use of a fiber laser with a large beam diameter and a top-hat beam profile. Although both approaches result in an improved weld quality, in terms of weld appearance, porosity and cracking, the resulting mechanical properties differ considerably. The addition of vanadium leads to a local increase of microhardness in the fusion zone. However, the tensile strength of these joints is lower as for fiber laser welded joints. In direct comparison fiber laser welded joints exhibit also higher formability as the joints welded with vanadium foil. The highest formability is obtained for dissimilar joints with the medium-strength Al-Mg alloy. Due to the unavoidable softening in the weld zone of heat treatable aluminum alloys, the formability of the joints is inferior in comparison to the base materials. In addition, the positive effect of post-weld heat treatment, surface milling and warm forming on the resulting mechanical properties of similar and dissimilar joints is discussed.

1. Introduction

High-alloyed Al-Zn-Mg-Cu alloys, with a (Zn + Mg + Cu) content above 10 wt.%, are generally assumed to be non-weldable by fusion welding techniques, such as laser beam welding (LBW) [1]. The laser weldability problems are characterized by an inferior outer appearance of the weld, mainly due to the expulsion of weld metal during laser beam welding, and by high porosity as well as severe cracking [2,3]. Solely by solid state welding, such as friction stir welding, defect-free weld seams can be achieved [4]. However, solid state welding is often not common or even not applicable for high-capacity industrial productions, due to its difficulties to weld complex structures and to control tolerances [5,6]. Because of their high strength in combination with a low density, Al-Zn-Mg-Cu alloys are promising materials for light-weight structures in the automotive industry, especially in comparison to steels (Fig. 1). Since laser beam welding is already established in the automotive industry as an efficient joining technology for series production, the laser weldability and adequate resulting mechanical properties have to be proved before the implementation of a new material to production. Al-Mg and Al-Mg-Si alloys exhibit acceptable laser weldability and a good formability. For this reason, these medium-strength aluminum alloys are predominantly used in the automotive industry for the substitution of steel, whereas high-strength Al-Zn-Mg-Cu alloys are currently unrecognized [7,8].

Besides light-weighting, the tailoring of structural properties is of great importance for the automotive industry. In this regard, the laser beam welding of dissimilar joints, so-called tailor-welded blanks (TWB), becomes necessary. The sheets can differ in their thickness, temper condition as well as in their chemical composition, so that locally different mechanical properties of the welded structure result [9]. A secondary effect of this tailoring is the saving of structural weight. However, due to changed chemical composition of the melt, the weldability of dissimilar joints may also alter. For this reason, most often similar weldable aluminum alloys with differing sheet thicknesses or temper conditions are preferred for fusion welding [10–13,15,16]. In case of friction stir welding, theses weldability problems for dissimilar joints were not observed [17]. In contrast to steel, all precipitation-hardenable aluminum alloys exhibit softening in the weld zone, which is increasing with increasing strength for high-strength aluminum alloys [19,20]. This has an

* Corresponding author at: Helmholtz-Zentrum Geesthacht, Institute of Materials Research, Materials Mechanics, Max-Planck-Straße 1, 21052 Geesthacht, Germany.
E-mail address: josephin.enz@hzg.de (J. Enz).

http://dx.doi.org/10.1016/j.jmapro.2017.07.030
1526-6125/

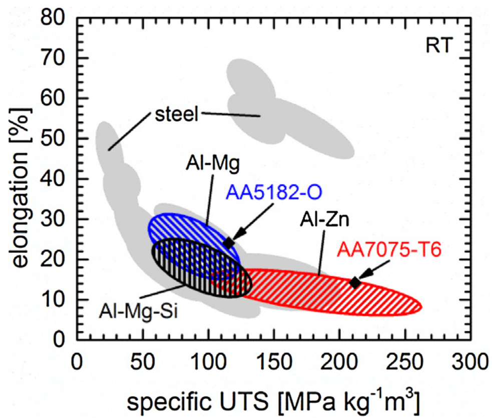

Fig. 1. Elongation and specific ultimate tensile strength of different aluminum alloys for the automotive industry in comparison to steels (according to van Nieuwerburgh [8]).

influence on the resulting formability of the TWB and represents, besides the weldability, the second challenge to be coped before the implementation of high-alloyed Al-Zn-Mg-Cu alloys.

Recently, two approaches were developed by the authors [21,22] for improving the laser weldability of high-alloyed Al-Zn-Mg-Cu alloys. Therefore, the thermophysical properties of the main constituents of these alloys during laser beam welding were examined and their influence on laser weldability was deduced. It turned out that the use of an adequate filler material can positively influence the thermophysical properties of the melt. Vanadium, for example, increases the surface tension and viscosity of the melt, decreases the beam irradiance and contributes to the balance between keyhole and vapor pressure. By this first approach, the keyhole stability during laser beam welding and thus the weld quality can also be improved [21]. This positive effect on the laser weldability could not be achieved solely by the use of a conventional aluminum alloy filler wire, since the thermophysical properties are only marginally different. Moreover, its effect on the resulting mechanical properties is also very limited [14]. In case of the second approach, the keyhole stability is improved by the use of a high-power fiber laser with an enlarged beam diameter, a top-hat beam profile and a high beam quality. Thus, the beam irradiance is decreased and the pressure balance achieved. And although no additional filler material is used for laser beam welding, the weld quality can be improved too [22]. The effectiveness of both approaches was demonstrated for similar joints even for very high alloyed Al-Zn-Mg-Cu alloy, such as AA7034 [21,22].

In the present study, the characteristics of the Al-Zn-Mg-Cu alloy joints welded with both developed approaches are compared with special regard to the resulting mechanical properties. Besides similar joints of an Al-Zn-Mg-Cu alloy, dissimilar joints with an Al-Mg alloy were laser beam welded in order to examine the capability of the approaches for the manufacturing of TWB's. In this regard, the challenge lies in combining materials exhibiting clearly different weldability and mechanical properties. Moreover, options for improving the mechanical properties of the joints, such as post-weld heat treatment, surface milling and warm forming, are examined. This allows the assessment of the potential of high-alloyed Al-Zn-Mg-Cu alloys for the use in the automotive industry.

2. Materials and experimental procedure

2.1. Base and filler materials

The precipitation-hardenable Al-Zn-Mg-Cu alloy 7075 was used for the welding of similar joints. For the dissimilar joints, the naturally aged Al-Mg alloy 5182 was used. By this means, a high-strength material was combined with a material of high formability in a tailor-welded blank. The sheet thickness of both alloys was 2 mm. The chemical composition as well as the temper condition of both alloys is given in Table 1.

Table 1
Chemical composition (in wt.%) and temper condition of the used aluminum alloys.

alloy (temper)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA7075 (T6)	0.4	0.5	2.0	0.3	2.9	0.28	6.1	0.2	Bal.
AA5182 (O)	0.2	0.35	0.15	0.5	5.0	0.1	0.25	0.1	Bal.
AA5087 (–)	0.25	0.4	0.05	1.1	5.2	0.25	0.25	0.15	Bal.

For the welding of the first approach 99.8% pure vanadium was used additional to a conventional filler material. Therefore, a vanadium foil with thickness of 40 µm was laser tack welded on the face side of one sheet, in order to ensure the position of the foil during welding. Moreover, the commercial Al-Mg filler wire 5087 (Table 1) with a wire diameter of 1.0 mm was fed during welding. In contrast, no specific filler material was required for the second approach.

Prior to welding, the surface of the aluminum sheets was mechanically grinded and cleaned subsequently with alcohol. In this way, the oxide layer as well as surface contaminations were removed to eliminate a possible source for hydrogen-induced porosity.

2.2. Laser beam welding

The two approaches for improving laser weldability imply the use of two different laser systems. A medium-power Nd:YAG laser – widely used in the industry – with a small beam diameter of approximately 366 µm and a Gaussian beam profile was used for the implementation of the first approach, since no special requirements on the laser system were made. For the second approach a high-power Yb fiber laser with a beam diameter of 746 µm, which is twice as large as of the Nd:YAG laser, and a top-hat beam profile was employed. The characteristics of both laser systems are specified in Table 2.

The laser beam welding process parameters given in Table 2 were optimized for each approach with regard to the weld quality. The defocusing of +7.5 mm in case of the second approach led to a further increase of the beam diameter to 882 µm. In addition, a higher laser power was required, due to the larger interaction area of the laser on the sheet surface. Although different aluminum alloys were used, no adjustment of the welding parameters was required for the dissimilar joint. For both joint configurations, the weld line was oriented longitudinal to the rolling direction of the sheets.

Table 2
Laser systems and parameters used for welding of the similar and dissimilar joints.

property	1st approach	2nd approach
laser type	Nd:YAG	Yb fiber
wavelength	1.064 µm	1.070 µm
beam parameter product	14.528 mm mrad	11.305 mm mrad
fiber diameter	300 µm	300 µm
focal length	250 mm	300 mm
collimator length	200 mm	150 mm
laser spot diameter (in focus)	366 µm	746 µm
Rayleigh length	4.63 mm	24.55 mm
irradiance distribution	Gaussian	top-hat
laser power	2.0 kW	3.0 kW
focus position	0 mm	+7.5 mm
welding speed	3500 mm/min	3500 mm/min
feed rate of filler wire	3000 mm/min	–
flow rate of shielding gas	20 l/min	20 l/min