WELDING OF ALUMINIUM COMPONENTS IN AUTOMOTIVE INDUSTRY

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Ključne riječi: *zavarivanje laserskom zrakom, aluminij, klima uređaj, automobilski.*

Sažetak

Rad se bavi povećanjem produktivnosti u proizvodnji funkcionalnih dijelova klimatizacijskih sustava. Izvorna tehnologija za gašenje požara ne zadovoljava potrebnu produktivnost i ne zadovoljava zahtjeve zaštite okoliša. Kao prikladna tehnologija za spajanje funkcionalnih dijelova klima uređaja, predložena je laserska zavarivanja. Zabilježeni su parametri zavarivanja kao što su žarišna duljina, laserska snaga, oblik i duljina laserskog impulsa, brzina zavarivanja (vrijeme), vrijeme punjenja, preklapanja zavarivanja, vrsta i količina plina. Rezultati ispitivanja vlačne čvrstoće, ispitivanja rupture i ispitivanja curenja helija pokazali su dovoljnu kvalitetu zavarivanja.

Keywords: *laser beam welding, aluminium, air conditioning, automotive.*

Abstract

The present work deals with the productivity increase in the production of functional parts of air conditioners. The original technology of flame brazing does not provide required productivity and does not meet environmental requirements. As a suitable technology for joining the functional parts of air conditioners the laser beam welding was proposed. Welding parameters like focal length, laser power, shape and length of laser pulse, welding speed (time), feeding time, weld overlap, type and amount of gas were evaluated. The results of tensile strength test, burst test and helium leakage test showed sufficient weld joint quality.

1. Introduction

The automotive industry is facing demands simultaneously to increase its fleet average fuel economy and to reduce the emission of greenhouse gases by its products. In order to meet these new standards, the industry is increasingly aiming to decrease the weight of vehicles through the use of new materials, especially lightweight aluminium alloys [1].

Fig. 1 Air conditioner component - braze joint [2]

Aluminum can be joined with almost all available welding methods as well as brazing. Nevertheless, the joining of aluminum and its alloys is a long-lasting problem solved throughout the world, because each alloy has specific properties due to its chemical composition. This chemical composition then brings various technological limitations and problems with weldability. The most common defects during welding of aluminum are porosity and cracking. Aluminum and its alloys are increasingly used in various industries due to their properties. In an automotive industry, for example, it is used in the production of air conditioner components that were recently flame brazed. Figure 1 shows the aluminum components of the air conditioner brazed with aluminum solder.

Using a corrosive flux in the form of a paste resulted in the partial oxidation of the brazed surfaces and the joint porosity. The flux residues should have subsequently been rinsed with other chemicals. This cleaning is not only a burden on the environment, but also a further operation in the production process and additional costs associated with the procurement and disposal of chemicals. Figure 2 illustrates propane-butane flame brazing using.

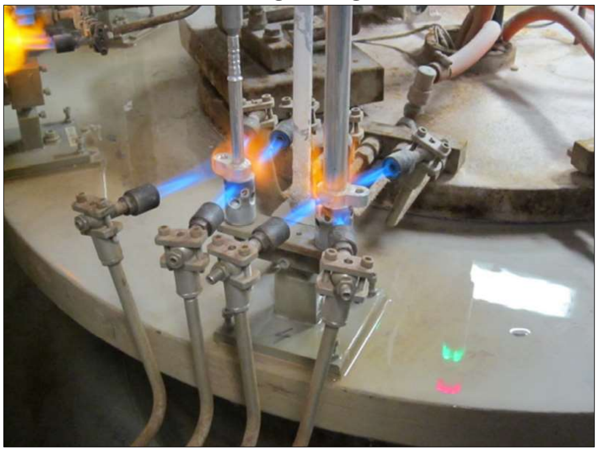

Fig. 2 The close-up of component heating during flame brazing

Fig. 3 illustrates the cross section of brazed joints. One of the evaluation criteria is infilling the capillary gap, because brazing often causes insufficient filling of the capillary gap and the formation of pores. The first joint in Figure 3 exhibited solid joint with a porosity in bottom part, however two other joints shows very poor quality of brazed joints. The cause of these defects can be in uneven heating of the material during brazing, improper braze, inappropriate gap width, and in misalignment of the pipe against the peanut.

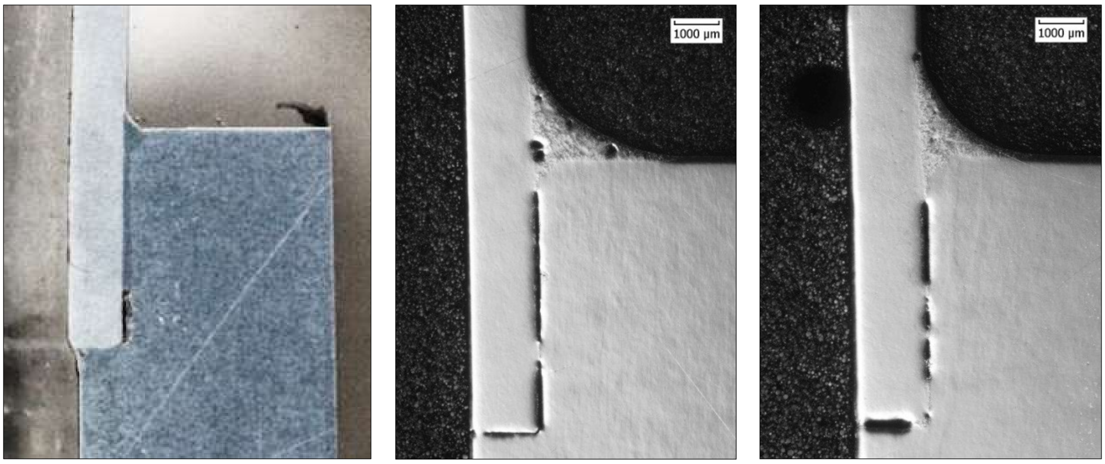

Fig. 3 Macroscopic analysis of brazed joints

Despite the excessive porosity, braze provided sufficient mechanical properties and joints, which resulted in the long-term use of this technology. The increasing pressure on lowering the production costs along with the greening of production was the main reasons for seeking an alternative technology. Primary requirements were to achieve high bond strength and tightness, ability of automation, higher productivity and minimal environmental impacts of newly-selected technology. Among the wide range of possible alternatives, all the required conditions have been met by laser beam welding.

The industrial application of lasers has been implemented successfully in the early 1970s. Since then, the laser became an increasingly used flexible tool. During the last two decades, laser welding has developed to a key assembly technology in the automotive industry [3].

2. Methods

With regard to 18 mm tube diameter and 1.5 mm wall thickness, laser beam welding was proposed as an alternative technology. The device used for welding was a Trumpf TruDisk 4002 disc laser source with an optical fibre diameter of 200 μm. Fig. 4 a,b shows the assembled components (peanut and tube) and the experimental setup during welding (Figure 4c). To provide rotational movement, a rotational positioner controlled by a robotic arm with Trumpf D70 welding head was used. Technically pure argon at a flow rate of 6 l/min was used as a shielding gas.

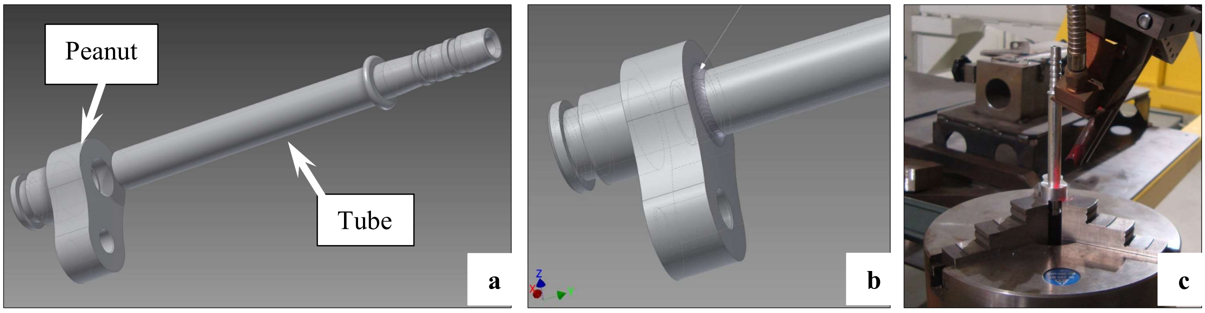

Fig. 4 The close-up of component heating during flame brazing
a) components assembly b) proposed weld joint c) experimental setup

Due to the design of the joint, the inclination of the welding head was 15°, i. e. as low as possible on the bottom peanut. The reason was the maximum depth of the penetration and minimal damage of the welded tube. Regarding the permissible dimensions of the weld joint, only 75% of the wall thickness of the tube can be melted and the peanut penetration depth can be up to 60% of the tube wall thickness. The minimum weld size must be greater than the tube wall thickness.

The uniformity of the weld bead surface was at first evaluated by visual inspection. Subsequently, the weld joints were cut at a critical location where the weld was terminated, and the sections were subjected to macroscopic analysis. Samples for macroscopic analysis were prepared by standard metallographic procedures and etching in Keller's reagent. Satisfactory joints were subjected to tensile strength, pressure and helium tests.

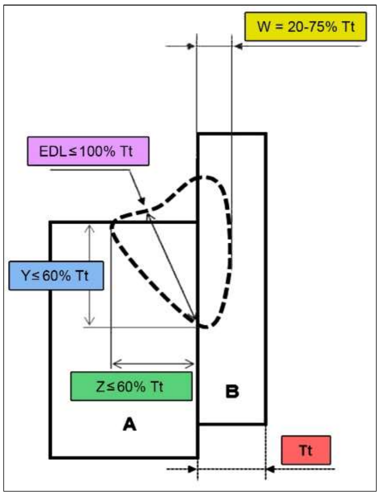

Fig. 5 Evaluation criteria for weld joints

3. Results

Originally the laser welding without using the filler material was proposed. However the results (Figure 6) showed that the high concentration of the energy caused the collapse of inner wall of the tube as well as its thickness reduction. Since the reduction was too big, the crack has appeared. Solidification cracking is a major concern during laser welding of aluminum alloys [4, 5, 6, 7, 8]. Besides, the wall damage was not symmetrical along the longitudinal axis of weld joint. The high thermal conductivity of aluminium caused gradual temperature increase during the welding process. This resulted into different preheat of material in overlapping area of the weld joint.

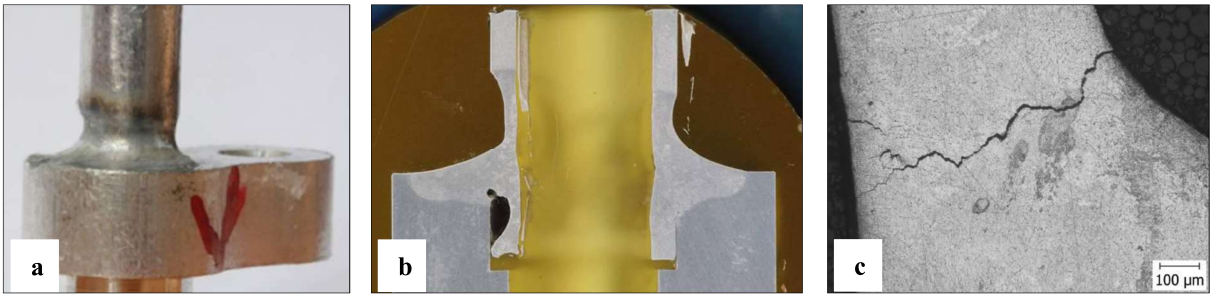

Fig. 6 Tube wall distortion after LBW without filler material
a) undercut b) tube wall thickness reduction c) crack close-up

Based on these results, the standard AlSi12 filler wire of 1.2 mm in diameter was used in welding process. After several process modifications the results showed persistent damage of inner wall of the tube as it is illustrated in Figure 7. Moreover, at the end of the weld joint (overlapping area), the helium leakage test revealed the critical porosity therefore the modification of the laser pulse was taken into account. Because of these phenomena the pulse shape was adjusted in further experiments as well.

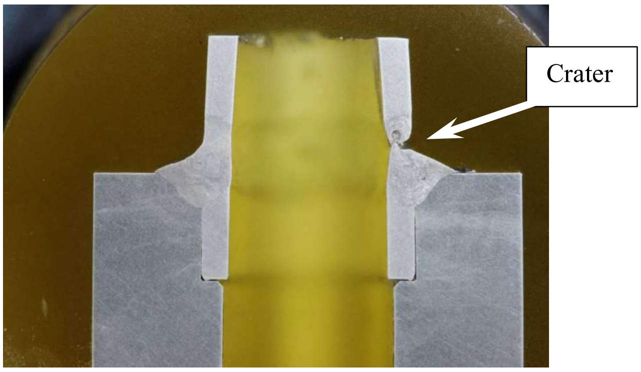

Fig. 7 Weld joint cross-section

The positon of laser beam was moved from the corner 0.2 mm towards the peanut to avoid excessive inner side tube distortion. To prevent crater formation at the end of the welding process, feeding time was prolonged to fill the crater. Parameters range used in further experiments are shown in Table 1.

Table 1 Range of parameters used in experiment

Laser power [W]	Welding time [ms]	Focus point position [mm]	Feeding rate [m/min]	Feeding time [ms]	Feeding delay [s]
1400 - 1800	1600 - 1800	-1 / -3	3,2 – 3,5	1400 -1700	0 - 0,5

In regard to mentioned preheating of the material during the welding process, the laser power was reduced to 85% of its maximum at the 95% of welding time. Moreover, to avoid the crater formation at the end of the weld joint, another decrease of laser power was involved (Figure 8). This pulse modification was tested on approximately 20 samples to obtain the suitable pulse shape.

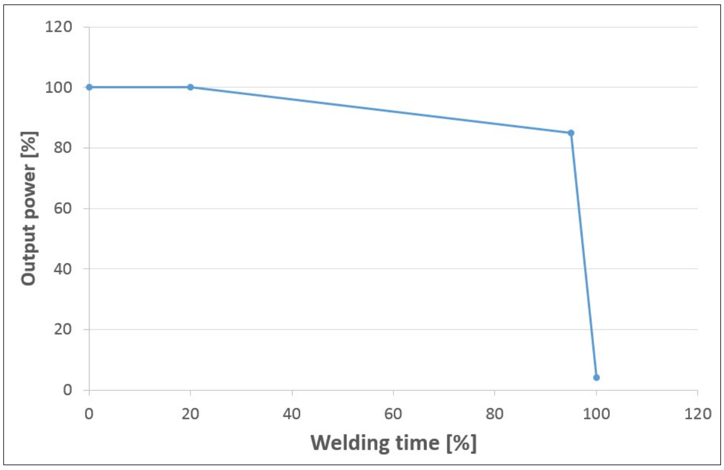

Fig. 8 Laser pulse adjustment

The optimal set of parameters from the proposed range was as follows: laser power of 1700 W, welding time 1700 ms, feeding time 1550 ms, feeding delay of 200 ms, feed rate of 3.3 m/min and focus point position of 3 mm below the surface. Weld bead appearance and the overlapped area are shown in Figure 9. The weld bead had regular shape with fluent transition to the base material. The crater formation in the overlapped area was significantly reduced (Figure 9 right) and weld bead width was continuously narrowed.

Fig. 9 The close-up of component heating during flame brazing

Subsequent macroscopic analysis (Figure 10) showed sufficient weld penetration and lack of voids in weld metal and heat affected zone. The distance from the weld surface to weld root was 15% higher than required value. Penetration of approximately 20% into tube wall and approximately 1.5 mm into the peanut was observed.

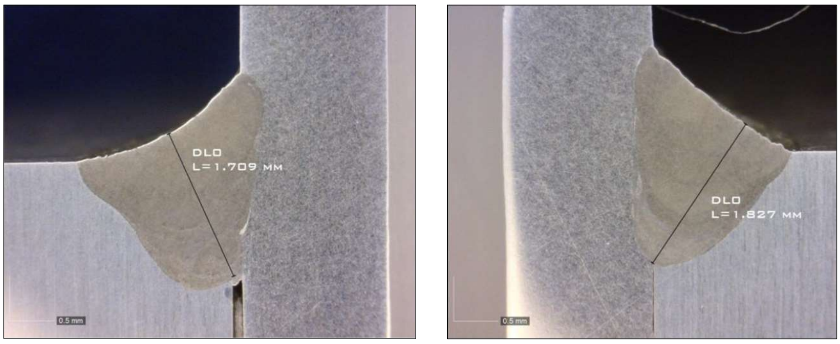

Fig. 10 Macroscopic analysis of laser weld joint

Tensile strength test on three samples (randomly selected from pre-production series) was realised in order to compare the strength with brazed joints. Minimal tensile strength required for brazed joints were 2000 N, however the strength of the samples joined by welding were more than two times higher. The results of tensile strength test are provided in Table 2.

Table 2 Results of tensile strength test

Sample number	Required strength [N]	Measured strength [N]
11	2000	4671
86		4611
162		4650

Since the air condition units operate under pressure, they have to be tested by pressure test. Nominal value for brazed joints was 13.7 MPa. Laser welded joints exhibited almost three times higher maximum pressure during the burst test. Results of the burst test are shown in Table 3. The tightness of the weld joints was examined by helium leakage test, which proved the joints as suitable.

Table 3 Results of burst test

Sample number	Required pressure [MPa]	Maximum pressure [N]
37	13.7	39.05
117		39.13
184		39.12

Replacing of the brazing technology by laser beam welding had significant impact on productivity as well as the cost saving of production. The time necessary for production of one joint by laser beam welding was 7.5 times lower in comparison brazing process. The production time for one brazed part was 22.5 seconds, whereas the time necessary to produce the welded part was only 3 seconds. The amount of parts produced during one shift raised from 1200 (brazed) to 9000 (welded).

4. Conclusions

The automation of production reduces defects caused by human factor and brings increase of productivity. On the other hand, the cost of equipment is usually much higher. The results of macroscopic analysis as well as other analyses confirmed the suitability of proposed laser beam welding to replace the brazing process.

Disk laser used in the experiment is a universal tool providing a good quality of laser beam as well as low operating costs. It is suitable for welding metals as well as plastic materials, what could widen the company portfolio of services.

Replacing the brazing by laser beam welding lead to increase of productivity more than 7 times. Moreover, proposed technology lowers the negative effect on environment.

5. Acknowledgement

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