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ALUMINUM ALLOY WELDING IN AUTOMOTIVE INDUSTRY

Summary. The paper presents the possibilities of using light alloy components in vehicle construction. Material 6082 was chosen for use in responsible structural components. The structure and strength parameters of the material in the delivery state were tested. Tested material parameters were compared with normative requirements. The purpose of the paper is to check the mechanical properties of aluminum alloy welded joints by various processes and parameters. Until now, welding of 6082 alloy did not give good and repeatable results. Because of that, two welding methods were analyzed (MIG and TIG) in the field of the quality of welds, strength of welded joints, and material structures obtained as a result of welding with various parameters.

1. INTRODUCTION

The increasingly stringent environmental protection standards that limit the emissions of harmful compounds contained in exhaust gases into the atmosphere oblige the automotive industry to look for a wide range of effective solutions. The major opportunity to reduce emissions might be achieved through the use of modern drives and reduction of vehicles' weight.

Car body components are important structural elements often manufactured with a welding technology. When properly designed, they improve the active and passive safety of vehicle and affect comfort and drivability. Wide accessibility, in-depth expertise of the joining processes, and experience in the use of steel materials make most car companies to focus on steel as the main element of vehicles' construction components. Currently, three types of car body welding structures are designed and applied. In a frame type (not bearing) body, the whole structure is based on a rigid frame that carries static and dynamic loads [2]. This type of construction is currently used mainly in trucks, vans, buses, and off-road vehicles. Formerly, it was also adopted in the construction of passenger cars but abandoned eventually owing to the large weight of the vehicles. At the same time, the frame was characterized by high stiffness and durability. The semi-elevating body is based on a composite frame, designed to carry some of the loads, whereas the remaining part of the loads is taken over by the body itself [1]. Such kind of body was formerly perceived as the most novel frame construction, but currently, it is almost unused in the production of European passenger cars and applied only sometimes in passenger cars constructed for the US market. The type of bodies most often designed in Europe for passenger cars are self-supporting bodies. Such type of body does not have a typical separate frame but a spatial truss system integrated in the body, usually made up of sheet metal profiles and sections. All of the static and dynamic loads are taken over by the body itself [1]. An undoubted advantage of this type of body is its relatively small mass in relation to its strength. Car body structures of this kind are nowadays often used in bus designs (Fig. 1).

The car manufacturers are looking nowadays for solutions that would further reduce the weight of vehicles through the use of new materials.

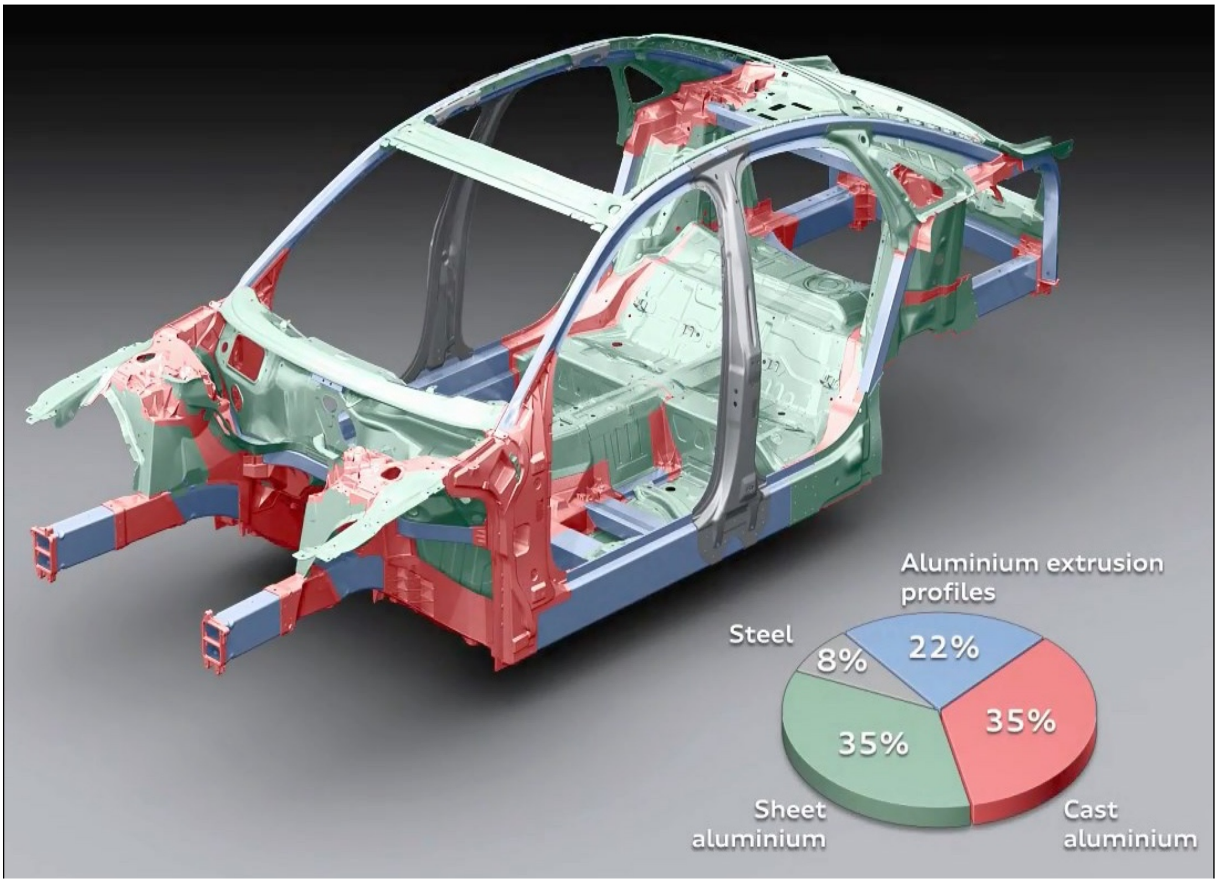


Fig. 1. Aluminum frame in self-supporting car -body structure [11]

The employment of lighter and equally durable components for suspension elements and frames helps to accomplish this goal. Manufacturing of vehicles' welding frames or their parts from light alloys reduces their weight and improves driveability [3].

The most important structural components of the vehicle are made predominantly from aluminum and very often these are welded structures [4-5]. On the car body, alloys from the 5xxx and 6xxx groups are more and more often used; however, welding problems occur [6-7]. Usually, it is proposed to weld these alloys TIG and MIG process, and the best parameters and ways of welding these alloys are still being sought [5-8].

2. SELECTION OF MATERIAL FOR RESEARCH

As a result of chemical composition, usability and technological properties, the car body structures are most commonly made from aluminum alloys belonging to the following groups: 2XXX, 5XXX, 6XXX, and 7XXX. The general information regarding their composition, strength, and weldability is summarized in the Table 1.

Alloys from 2XXX and 7XXX groups characterize with the most favourable mechanical properties (very high ultimate). However, for technological reasons, the susceptibility to welding is best for materials from groups 5XXX and 6XXX.

Table 1

Aluminum alloys used in the automotive industry (Source: own study)

Group of aluminum alloys	Main alloy components	Properties	Weldability
2XXX	Al – Cu	High durability	Hard to weld
5XXX	Al – Mg	Increased durability	Easy to weld
6XXX	Al – Si – Mg	Increased durability	Easy to weld
7XXX	Al – Zn	High durability	Hard to weld

Table 2 summarizes normative properties of exemplary alloys categorized into individual groups.

Table 2

Normative mechanical properties of selected aluminum alloys used in automotive industry (Source: own study)

Parameter	2017A	5083	6082	7075
Ultimate tensile strength, UTS, [MPa]	480-540	255-275	270-310	480-540
Yield point, YS[MPa]	390-470	105-125	200-260	390-470
Hardness [HB]	104-157	75	95	104-157
Elongation A_5 [%]	6-8	11-16	6-10	6-8
Density [g/cm^3]	2.80	2.66	2.70	2.80

To join aluminum elements, the automotive industry uses welding, heat-bonding, and gluing processes most frequently. Conventional welding of aluminum alloys does not create any major technological or executive difficulties [9]. There are no complications when producing good-quality aluminum joints in conventional, less-efficient slag-free welding processes [10]. Welding with a coated electrode however does not provide acceptable weld quality, as porous structures with a tendency to crack do appear. As a result, welding with coated electrodes is used very rarely and only on insignificant structural components (Fig. 2).

The most popular non-slag welding processes used on the industrial scale are TIG and MIG methods. In the TIG (Tungsten Inert Gas) method, an electric arc appears between a non-consumable electrode (usually made of tungsten) and a bonded material in an inert gas shield. In the TIG welding process, the use of any additional material is not required, but it is possible to use an extra binder. The binder material, usually available in the form of a wire, is introduced into the weld pool manually. Argon, helium, or Ar-He mixtures are most often selected to serve as a shielding gas. The gas is fed through the nozzle of the welding torch to protect both the weld and the electrode against oxidation and nitrification.

Fig. 2. Frame welded with the TIG method [12]

The MIG welding method is based on an electric arc produced between a consumable electrode and a bonded material in an inert gas shield. The electrode wire becomes the consumable electrode fed in an automatic and continuous way. The wire is selected in accordance with technological guidelines for a specific welded material (Fig. 3).

Fig. 3. Frame welded with the MIG method [13]

The advantages of MIG welding method are as follows:
- universality - the possibility of welding various types of alloys in all positions,
- high welding efficiency - higher from coated electrodes and TIG method,
- relatively low cost of welding consumables,

- high quality of welds, and
- possibility to automate the method.

The disadvantages of MIG welding method are as follows:

- quality of produced welds often depends on the skills of a welder,
- high purchase costs of equipment and accessories, and
- the necessity to use an additional binder.

The advantages of TIG welding method are as follows:

- - universality - the possibility of welding various types of alloys in all positions,
- - possibility to weld thin metal sheets,
- - high quality of welds,
- - easy control and handling of the welding process,
- - lack of liquid metal splashing,
- - lack of necessity to use an additional binder, and
- - possibility to automate the method in situation when additional binder is not used.

The disadvantages of TIG welding method are as follows:

- low welding speed and low efficiency, especially in case of thicker components,
- quality of produced welds depend on the skills of a welder, and
- lack of possibility to automate the method in situation when additional binder is used.

Despite the prevalence of advantages, welding of aluminum alloys with the use of non-slag processes still provides either insufficient functional properties of the joint or low relative efficiency, which was confirmed, e.g., by Haboudou, Peyre, and Vannes [14-15].

Fig. 4. Frame structure welded with the TIG method [13]

Owing to these factors, employment of aluminum alloys in vehicle constructions is not popular. For reasons of productivity, the cost of manufacturing vehicle's frame (Fig. 4) using traditional welding methods is very high in relation to widely used methods of joining vehicle frames with steel materials [16]. Fatigue strength tests should check that aluminum alloy welds are of good quality [17-18].

3. ANALYSING INFLUENCE OF WELDING METHOD ON STRUCTURE, QUALITY, AND MECHANICAL PROPERTIES OF ALUMINUM ALLOY WELD ON THE EXAMPLE OF 6082 ALLOY WELDING

It is vital to assess the effect of selected welding method on strength parameters of welds produced with TIG and MIG methods, in order to use the achieved results for further design and manufacturing of welded structural components in automotive vehicles that are made up of aluminum alloys. For the tests, the 6082 aluminum alloy was selected. As a result of its mechanical properties, the tested alloy could be used to make vehicle frames in the means of transport.

The samples used in the tests were made of metal sheet with dimensions 100 mm×200 mm and thickness 3 mm and 5mm. The butt welds were made using TIG and MIG methods. The samples were made to carry out the strength tests.

First, the chemical composition of delivered aluminum alloy samples was examined. It was confirmed that the tested material conforms to the normative content of alloying elements of EN 573-3 norm. The results are summarized in the Table 3.

Table 3

The chemical composition comparison of 6082 alloy in delivery condition with the EN 573-3 standard (Source: own study)

Alloy 6082	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
According to EN 573-3	0.7-1.3	Max 0.5	Max 0.1	0.1-0.4	0.6-1.2	Max 0.25	Max 0.2	Max 0.1
Sample	1	0.3	0.05	0.1	0.6	0.1	0.1	0.1

The prepared samples were tested out on the strength machine to determine their tensile strength parameters, yield point, and relative elongation. Samples were also tested for hardness. For the analysis, five samples prepared in the same way were used.

The examination was carried out on a ZWICK 100N5A strength testing machine. The average results are summarized in Table 4. It was found that the material conforms to the normative mechanical properties.

The structure of the tested aluminum alloy was examined. The image of the obtained structure is presented in Fig. 5. A typical non-heat treated aluminum alloy structure was found.

After the initial analysis of base material, the structure and strength parameters as well as the composition of the welds were further investigated.

Table 4

Comparison of the mechanical properties of 6082 alloy in delivery condition with EN 755-2 standard (Source: own study)

Alloy 6082	Tensile strength, UTS, [MPa]	Yield point, YS [MPa]	Elongation, A5 [%]	Hardness, HB
According to EN 755-2	Min 205	Min 110	14	58
Sample	208	112	15	65

It was decided to check the welding of alloy 6082 by two methods (TIG and MIG) and with various parameters. Information about MIG welding is presented in Table 5, and information about TIG alloy welding is included in Table 6. In case of MIG, welding parameters were on the typical level: a current was on the level of 230-235 A and an arc voltage on the level of 22-23 V was ensured. The welding speed was varied three times: 300, 500, and 700 mm/min, correspondingly. Two welding wires 4043 and 1450 (Al with 5% Si, and Al with 0.5% Ti, respectively) were tested.

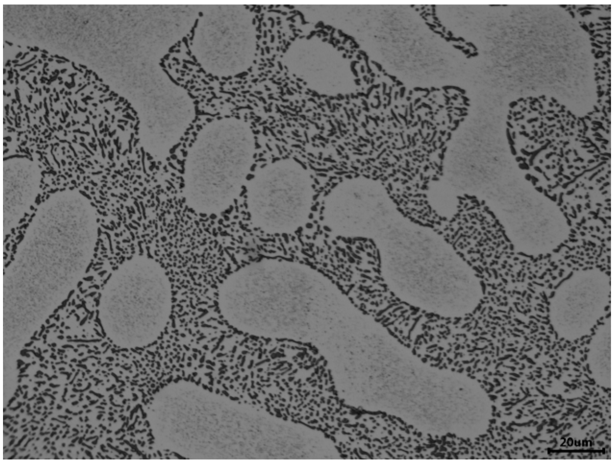


Fig. 5. The structure of 6082 aluminum alloy in delivery condition

Table 5

MIG welding parameters (Source: own study)

Parameters of process:	MIG
current, I [A]	230-235
voltage, U [V]	22-23
welding speed, V [mm/min]	300, 500, 700
type of welding wires	1450; (0.5% Ti); 4043; (5% Si)

Table 6

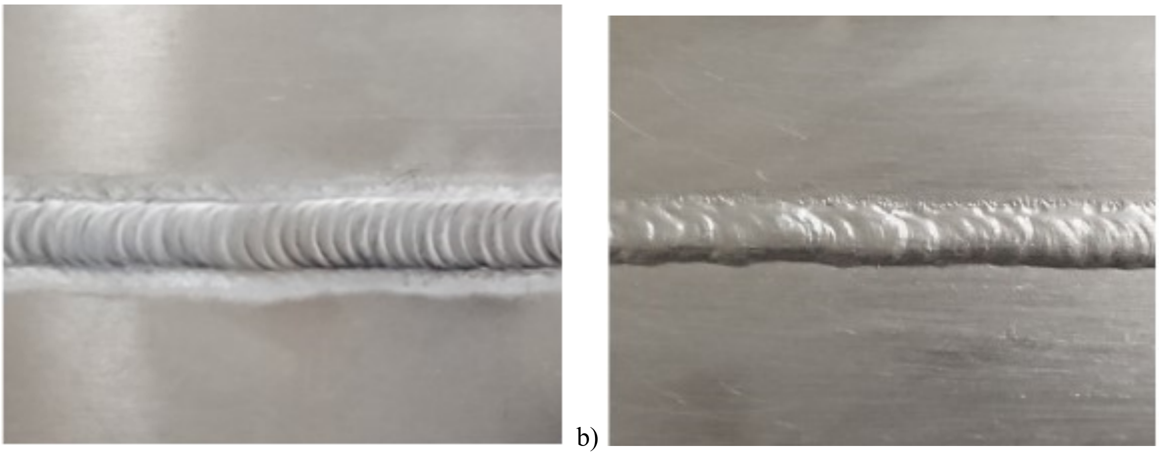
Parameters of the samples welding process with TIG and MIG methods (Source: own study)

Parameters of process:	TIG
Current, I [A]	150
Voltage, U [V]	16
Welding speed, v [mm/min]	50, 60, 70
Type of binder	Lack of binder

The appearance of samples (typical macrostructure) after welding is shown in Fig. 6.

For strength tests, five sheets welded together with butt beams using TIG and MIG methods were prepared. Exemplary samples are presented in Fig. 7. The samples were obtained by the parameters of the welding process, presented in Table 5. From the prepared sheets, samples for strength tests, carried out on a ZWICK 100N5A testing machine, were made with dimensions of 35 mm×400 mm and a thickness of 5 mm. Individual tensile tests were also carried out.

Samples after tensile tests are presented in Fig. 8. It was found that all samples began to deform in the area where the welds were made. Strong plastic deformations appeared around the joints and finally the sample cracked. The photograph (Fig. 8) shows deformed material around the welds as well as symmetrical (in relation to the weld) necking of samples in the heat-affected zone. The average values of the obtained measurements are presented in Tables 7 and 8.



a) b)

Fig. 6. Samples from 6082 aluminum alloy welded with different methods: a) TIG; b) MIG

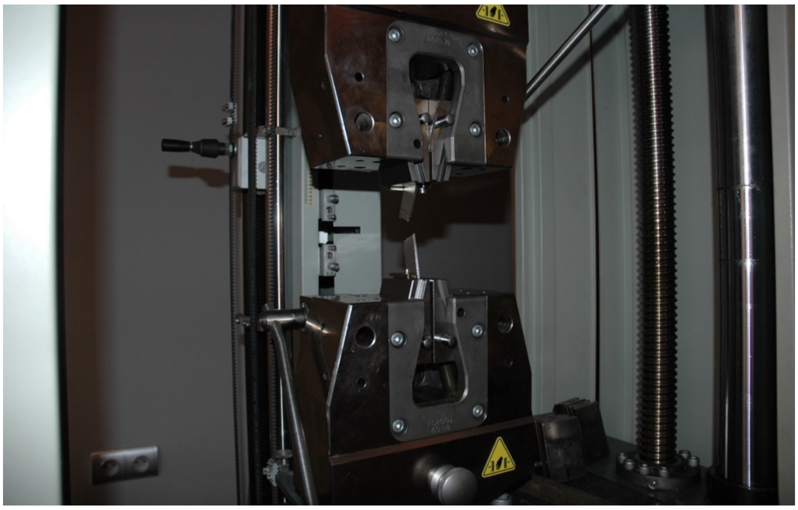


Fig. 7. Tensile test carried out on a ZWICK 100N5A type machine

Fig. 8. Samples from alloy 6082 after rupture

Analyzing the data from Table 7, it is easy to deduce that tensile strength and yield point are comparable regardless of the various MIG welding speed and the type of electrode wire that was adopted. Only the elongation was not at the same level. The welding speed of 500 mm/min can be considered as the most favorable. The wire with the addition of silicon gives slightly better results than titanium. Table 8 gives the influence of welding speed in the TIG process on mechanical properties of welds (an average of 3 measurements).

Table 7

Comparison of mechanical properties of 6082 alloy in delivery condition with mechanical properties of MIG welds (Source: own study)

Parameters	Tensile strength, UTS, [MPa]	Yield point, YS, [MPa]	Elongation, A_5 [%]	Hardness, HB
Wire 4043, v= 300 mm/min	212	141	7.2	81
Wire 4043, v= 500 mm/min	209	139	9.4	77
Wire 4043, v= 700 mm/min	213	140	6.8	79
Wire 1450, v= 300 mm/min	206	129	8.1	79
Wire 1450, v= 500 mm/min	210	139	9.1	77
Wire 1450, v= 700 mm/min	208	132	7.4	83

Table 8

Comparison of mechanical properties of 6082 alloy in delivery condition with mechanical properties of TIG welds (Source: own study)

Process	Tensile strength, UTS, [MPa]	Yield point, YS, [MPa]	Elongation, A_5 [%]	Hardness, HB
v= 50 mm/min	217	147	8.3	82
v= 60 mm/min	215	142	9.0	78
v= 70 mm/min	219	149	8.2	83

Analyzing the data from Table 8, it is easy to deduce that tensile strength and yield point are comparable regardless of the various TIG welding speed. Only the elongation was not at the same level. The welding speed of 60 mm/min can be considered as the most beneficial. Then, it was decided to perform a bending test (Table 9.) for welds that were characterized by good elongation on the level of at least of 9%. Therefore, two MIG welds (corresponded with wire 4043, v = 500 mm/min, and wire 1450, v= 500 mm/min) and one TIG weld (corresponded with welding speed of 60 mm/min) were taken into account.

Additionally, bending tests on 20 samples welded with MIG method and 10 samples welded with TIG method were carried out. Aluminum strips cut from the previously made welded samples 20 mm wide, 400 mm long, and 5 mm thick were subjected to analysis. The bending test was carried out until the parallelism of the arms up to 180 degrees was achieved. In the first case, the bending was performed from the face side (5 TIG samples and 10 MIG samples). Then the bending test from the root side was repeated. The results of the experiment are summarized in the Table 8.

It was found that cracking in the area of the weld and the native material does not occur in case of face-side bending, regardless of the selected welding method. Non-accidental cracks do occur however in the weld area in samples welded with the MIG method while bending from the root side. Similar cracks do not appear on the root side in case of TIG welded samples.

Table 9

The bending tests results for joints welded with MIG and TIG methods (Source: own study)

Process	Bending direction	Test result
MIG, wire 4043	Face side	Lack of cracks
MIG, wire 4043	Root side	Lack of cracks
MIG, wire 1450	Face side	Lack of cracks
MIG, wire 1450	Root side	Cracks
TIG	Face side	Lack of cracks
TIG	Root side	Cracks

Bending tests allowed to narrow down the search for the most appropriate welding parameters of 6082 alloy. The most advantageous process is MIG using 4043 wire and welding speed of 500 mm/min. Finally, it was decided to check the joint structure with the most advantageous parameters (which guarantee high relative elongation and complete absence of cracks) (Fig. 9).

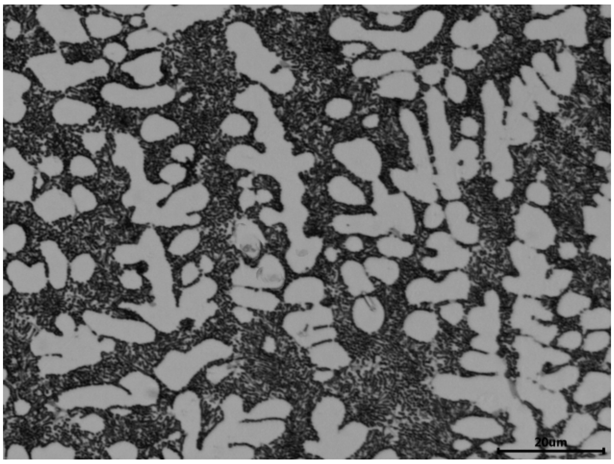


Fig. 9. The structure of aluminum alloy 6082 weld made with MIG method

In this case, the typical structure with separated β-phases is observed. The grain in the weld is clearly smaller (Fig. 9) than in the base material (presented in Fig. 5).

The last stage of experimental procedure was focused on fatigue tests. Three samples after TIG and MIG welding were examined (wire 4043 only). High cycle stress-controlled four-point bending fatigue tests were carried out using Cracktronic resonant testing machine from RUMUL. Rectangular cross-section specimens were tested having standard dimension and notch of Charpy's test requirements. In this case, a four-point bending test of rectangular, notched V-notched specimens under fatigue loading was selected under the control of testing machine by means of a cyclic force signal in a form of sinusoidal function. It was accepted for implementation at a further stage of the research work - another experimental evaluation of the fatigue life of the examined alloy welds. In the case under consideration, an estimation was made of the number of loading cycles at which a crack would occur

(3 measurements). The analysis used the nominal stress value of 100 MPa at frequency of 4 Hz. Results are presented in Table 10.

Table 10

High cycle stress-controlled four-point bending fatigue tests (Source: own study)

Sample (3 measurements)	Cycle counter at the end of the test
TIG 1	5 718 742
TIG 2	5 634 890
TIG 3	5 700 735
MIG 1	6 434 219
MIG 2	6 434 890
MIG 3	6 300 735
6082 alloy 1	9 110 234
6082 alloy 2	9 037 373
6082 alloy 3	9 084 213

Analyzing the values, it can be stated that fatigue life is at a high level but lower than base material. The results of testing the fatigue strength of welds indicate that MIG welding gives better effects than the TIG process.

4. CONCLUSION

The paper examined and presented the possibilities of using 6082 aluminum alloy in automotive industry. The available literature, technical information, as well as conducted tests prove that it is possible to use this material to manufacture important structural components of vehicles. Strength parameters obtained as a result of material bonding with the use of TIG and MIG methods in the weld area as well as the heat-affected zone do not prevent the use of 6082 alloy for structural components of vehicles. In case of both welding methods, an increase in tensile strength and in the value of yield point in the weld area was observed. The cracking of the samples occurred outside of the weld area, while the exact location indicated the propagation of neck under tension in the area of the heat-affected zone. TIG welding might be suggested as more advantageous owing to obtained weld strength parameters. On an industrial scale, however, the TIG method is not recommended for technological reasons and relatively low welding speed. Further studies are necessary to develop new welding technologies that would eliminate issues resulting mainly from technological limitations of the presented methods. The use of new, faster, and at the same time precise welding methods would allow to expand the use of aluminum alloys for vehicle constructions and promote reduction of production costs of light alloy components. The results of tensile strength and fatigue strength of aluminum alloy 6082 welds indicate that MIG welding gives better effects than the TIG process.

As the main conclusion of the work, the following can be stated:

- The properties of 6082 alloy make this material applicable for civil engineering and transport needs.
- TIG and MIG processes are suitable for welding 6082 alloy.
- The most favourable effect of welding 6082 alloy can be obtained after MIG welding using 4043 wire. The welding speed should be on the level of 500 mm/min.

Acknowledgments

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