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MODERNIZED MAG WELDING AND STAMPING FOR HEAVILY LOADED TRUCK CHASSIS COMPONENTS

Summary. Both the processes of welding and stamping are becoming increasingly more common in the construction of means of transport. Heavily loaded vehicle components should have good plastic properties so that cracks do not occur under operating conditions. Welded joints often crack, especially when they are subjected to additional treatments, such as stamping. In this article, the possibility of MAG welding (Metal Active Gas) of low-alloy steel using (MJC) micro-jet cooling was checked. Then, the made joints were subjected to a stamping test. Weld metal deposit (WMD) was carried out for the classic MAG process and compared with the modern method using MJC. Joint sand stamping tests of low-carbon and low-alloy steel were carried out. Welding with micro-jet-cooling could be considered promising due to the useful structure of WMD. This structure yields better mechanical properties, i.e. higher impact toughness for subzero service. For the first time, it was decided to check the pressure of the sheets welded with an innovative welding process. Then, the samples obtained by welding were subjected to the process of stamping. The result of stamping of welded sheets was investigated. The results of stamping show that only after correct welding process might the expected mechanical properties be achieved.

1. INTRODUCTION

Heavily loaded chassis components for trucks are increasingly being made often by welding and stamping. The casting technology in this case is not recommended. It is much easier to make such elements by primary welding and then by stamping because it is easier to weld a flat surface than

a curved surface after a stamping test [1-2]. The manufacturing process such as extrusion, forging, and stamping can be supported by various methods, which enables to the deformation force value. The stamping process is constantly modified in order to obtain good quality of products [2-4]. Moreover, the modified process can be designed or redesigned in the laboratory using specimens and monotonic-cyclic loading combination capturing material response and values of mechanical parameters [3].
A steel structure such as a truck chassis or car-body must have both high tensile strength and good plastic properties. The measure for good plastic properties of thin-walled structures is the relative elongation, and the measure of plastic properties for structures with thicker walls is impact toughness [5-6]. Recently, attempts have been made to use welding processes equipped with a micro-jet injector as a joint technological process.

Use of MJC technology leads to welding with much better impact toughness compared with actual processes [7-10]. Proper plastic properties of welding depend on many factors. The mechanical properties of the joint are influenced by the type of welding process, which affects the thermal processes in the solidifying metal. The choice of the welding process affects the amount of oxygen, hydrogen and nitrogen in WMD.

Good joint properties are obtained especially in low-nitrogen, low-hydrogen and low-oxygen welding processes. In particular, the amount of N and O has a noticeable influence on the structure. Acicular ferrite (AF) formation is facilitated by the presence of oxide non-metallic and nitride non-metallic inclusions in the weld. The oxygen content in the WMD should not exceed 450 ppm, and the nitrogen content should not exceed 60 ppm [6]. The percentage of acicular ferrite directly corresponds with the high impact toughness of the weld [6, 10]. This phase is formed inside the previous austenite grain. Even with inclusions in WMD, it is only possible to obtain lower than 50 % of acicular ferrite in the weld [7]. MJC also promotes an increase in the percentage of acicular ferrite in the weld and consequently high impact toughness [11-13]. Micro-jet cooling was tested in steel welding by various micro-jet gases: argon, helium and nitrogen.

An important aim of this article (and its novelty) is to check whether the samples of thick joints welded with the welding process with micro-jet cooling can be subjected to the stamping process for the production of highly loaded chassis components for trucks.

2. BASIC DATA ON THE EXPERIMENTS

In the present paper, the following steps were taken achieve the objectives:

- the weldability of two different grades of steel (S355J2G3 and S235JR) with different carbon contents (0.13% C and 0.18% C, respectively) was checked,
- the mixed welding process of tested grades of steel (S355J2G3 together with S235JR) was checked and
- the stamping process was carried out for two grades of steel and for the mixed weld.

The welds were prepared by welding with and without micro-jet cooling. The chosen parameters of MJC were slightly varied:

- stream diameter (60 μm and 50 μm),
- gas pressure (only 0.5 MPa) and
- micro-jet gases (helium, nitrogen).

The second part of this research was performed using a hydraulic press with a maximum load of 250 Mg. The proper tools were used to obtain a cylindrical vessel.

3. RESEARCH

The research has been performed in two steps: first, welding of sheets for heavily loaded truck chassis components was performed and, second, the stamping process of the welds was performed. The aim of this research was to obtain two different grades of steel S355J2G3 and S235JR (with various contents of carbon: 0.13% and 0.18% C, respectively). Mixed joints from both grades of steel were also prepared. The welding samples had an unusual round shape due to the requirements for the stamping process. Samples were half-discs. The notation of sample geometry is shown in Fig. 1. The same notation is used for all the described processes i.e. welding with MJC and stamping. Diameter D of the sample is 110 mm and the width of the sheet g = 8.5 mm.

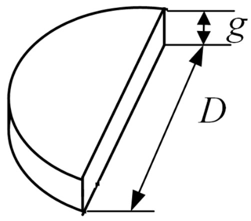

Fig. 1. Geometry of the sample

The edges of the elements to be welded (disc diameter) were prepared as follows:

- the sheets were chamfered on the single V groove,
- the gap (root opening) was 1 mm,
- V groove angle was 60 ° and
- a 6-stitch joint was made.

Welds of the classic MAG process with and without the use of MJC were compared. The main data of the parameters of the process are shown in Tab. 1.

Table 1

Parameters of the process

Parameters:	Values:
Diameter of the electrode wire	1.2 [mm]
Current	220 [A]
Arc voltage	24 [V]
Shielding gas	80%Ar-20%CO_2
Kind of MJC gases	He N_2
Micro-jet gas pressure	0.5 [MPa]
Micro-jet diameter	50 and 60 [μm]

The MAG method with MJC was precisely tested (Fig. 2.). He was chosen for the micro-jet cooling due to good cooling properties. Nitrogen was used for micro-jet cooling for economic reasons, mistakenly assuming that nitrogen would not affect the chemical composition of WMD and, consequently, the properties of the joint.

Various combinations of joints and their chemical composition are shown in Tab. 2.

It was observed that WMD in all tested cases had rather similar chemical compositions, except the amount of nitrogen, which clearly increased from 60 ppm to 75 ppm when N_2 was used for MJC.

The acicular ferrite in WMD has the greatest influence on the plastic properties of WMD and its impact toughness. After chemical examination, the structure analysis was carried out. Mainly, the amount of acicular ferrite was estimated, which is presented in Tab. 3.

Fig. 2. View of the welding station

Table 2

Composition of weld without the use of MJC

Element in WMD	S355J2G3 welding with MJC. Amount	S235JR welding with MJC. Amount	S355J2G3 welding with S235JR with MJC. Amount
C	0.13%	0.18%	0.16%
Mn	0.79%	1.1%	0.79%
Si	0.39%	0.46%	0.39%
Ni	0.2%	-	-
Cr	0.2%	-	-
Cu	0.1%	-	-
P	0.017%	0.019%	0.017%
S	0.018%	0.021%	0.019%
O	380 ppm	420 ppm	415 ppm
N	60 ppm	65 ppm	60 ppm
Al	0.015%	0.017%	0.016

Acicular ferrite in the tested deposits varied in composition. The positive strong effects of helium micro-jet cooling and the slight effect of nitrogen MJC on the acicular ferrite content could be easily observed. This effect is explained by the different λ conductivity coefficients for He and N_2, which is 143.4 J/cm·s·K for He and 23.74 J/cm·s·K for N_2.

Table 3

Amount of Acicular ferrite after welding

micro-jet cooling parameters: gas, diameter	AF in WMD after S355J2G3 welding, %	AF in WMD after S235JR welding, %	AF in WMD after S355J2G3 welding with S235JR, %
without cooling	45	40	45
He, 50 µm	60	55	60
He, 60 µm	57	53	58
N_2, 50 µm	50	45	50
N_2, 60 µm	48	42	52

Acicular ferrite is formed inside the grain of the previous austenite most often in contact with non-metallic inclusions that, in addition to Fe, contain Mn, Al or Ti. The presence of Ti was not found in the tested steels; thus, the formation of acicular ferrite may be influenced by non-metallic inclusions containing Mn and Al, such as $MnO \cdot Al_2O_3$ (galaxite), MnO and AlN. Impact toughness strongly depends on the amount, density and chemical composition of non-metallic inclusions. Inclusions with an average size of about 0.4-0.7 µm favor the formation of acicular ferrite. Larger non-metallic inclusions are unfavorable; they create the so-called welding defects and welding incompatibilities and negatively affect the plastic properties of the joint.

The analysis of obtained results shows that the content of Mn at the level of 1.1% and Al at the level of 0.016% is favorable for obtaining good joint impact toughness. Helium micro-jet cooling, in combination with the beneficial effect of small non-metallic inclusions, facilitates the transformation of austenite in acicular ferrite. It was found that too intense cooling is not beneficial, which corresponded to the selection of a wider diameter of the micro-stream. Nitrogen as MJC gas could be treated as a worse choice than helium also due to much higher amount of N in WMD (Tab. 4).

It has been observed that especially too intense nitrogen micro-jet cooling is unfavorable because it causes an increase in the nitrogen content in WMD.

Table 4

Nitrogen in WMD after welding with micro-jet cooling

MJC parameters: gas, diameter	S355J2G3 welding with MJC	S235JR welding with MJC	S355J2G3 welding with S235JR with MJC
-	60 ppm	65 ppm	60 ppm
He, 50 µm	60 ppm	65 ppm	60 ppm
He, 60 µm	60 ppm	65 ppm	60 ppm
N_2, 50 µm	65 ppm	70 ppm	65 ppm
N_2, 60 µm	70 ppm	75 ppm	70 ppm

In classic welding processes (i.e., without MJC), higher amount of grain boundary ferrite (GBF) is observed [15]; usually, a site plate ferrite (SPF) [15] fraction is also observed. Meanwhile, after welding with MJC, both grain boundary ferrite and site plate ferrite structures were not dominant.

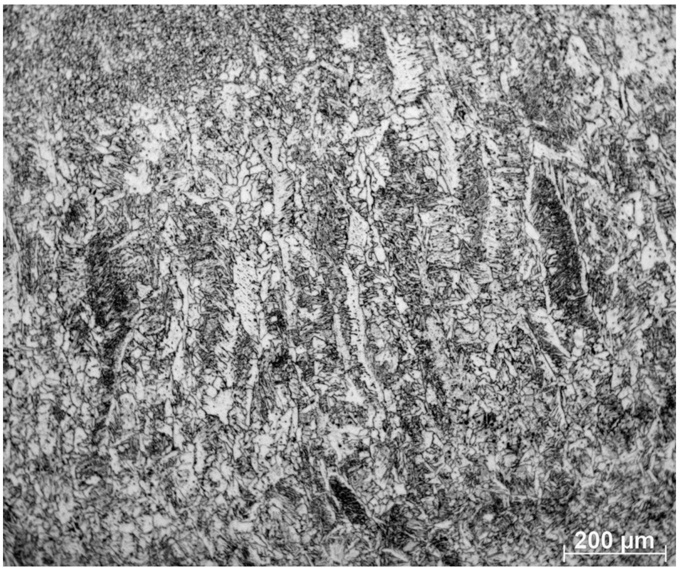

Fig. 3. Acicular ferrite in S235JR weld (60%) after He micro-jet cooling

In all joints, pearlite, martensite, retained austenite and non-metallic inclusions could be observed. 60% acicular ferrite could be obtained only in two cases, when helium micro-jet cooling was used (Fig 3). Fig. 3 shows that MJC has a noticeable influence on the structure because of the high amount of acicular ferrite. After the microstructure studies, the Charpy V impact toughness tests were carried out (average of 5 measurements). The Charpy tests were only carried out at two temperatures of - 20° C and +20° C. The samples were cut across the weld; the notch was made from the side of the weld face. The results of impact toughness are shown in Tab. 5.

It could be observed that impact toughness is apparently affected by different types of micro-jet gas. Due to the fact that there was no scatter in the results of the impact tests, no statistical analysis was performed in accordance with the standard.

The second part of the experiment involved the stamping process. The samples for this process were circles obtained by welding in the first stage of the experiment. The scheme of the samples is presented in Fig. 4. The diameter of the circle is 120 mm. The aim was to obtain a cylindrical vessel.

The stamping process was performed using a 250-T-PYE hydraulic press. The maximum stress applied during stamping equaled 250 MPa. Lubrication support was needed. Semi-liquid lubrication was applied. The kinematic thermal conductivity coefficient of lubricant equaled 44 mm^2/s. The sample was subjected to a cooling process. The process was performed at ambient temperature.

The experiment was conducted for every sample obtained for all combinations produced in the welding process. This means that 9 types of samples (presented in Tab. 6) were tested in the stamping process. For every type of sample, we observe that the dimensions of samples are almost equal to each other. There are small differences between the dimensions of the samples, but we the difference is caused by the nature of the process (in reality, it is not possible to ensure that the conditions of the process for every course are the same, i. e. lubrication) rather than use of different materials (the characteristics of the materials are very similar and have no influence on process flow).

Fig. 5 shows a picture of one of the obtained cylindrical vessels. It is the sample made of two parts of S235JR by welding with micro-jet cooling. The other samples look very similar. We can observe that the cylindrical vessel is produced with high precision. The anisotropy of the used sheet has no influence on the shape of the sample.

Table 5

Impact toughness of WMD

Welding process and materials	Micro-jet gases	Impact toughness KCV, J (at - 40° C)	Impact toughness KCV, J (at -20° C)	Impact toughness KCV, J (at +20° C)
S235JR – MAG welding	without cooling	below 47	61	179
S235JR – MAG welding with MJC	He	47	77	184
S235JR – MAG welding with MJC	N_2	below 47	59	171
S355J2G3 – MAG welding	without cooling	below 47	73	180
S355J2G3 – MAG welding with MJC	He	53	79	188
S235JR – MAG welding with micro-jet cooling	N_2	below 47	69	173
S355J2G3 with S235JR – MAG welding	without cooling	below 47	66	181
S355J2G3 with S235JR – MAG welding with MJC	He	49	77	193
S355J2G3 with S235JR – MAG welding with MJC	N_2	below 47	69	174

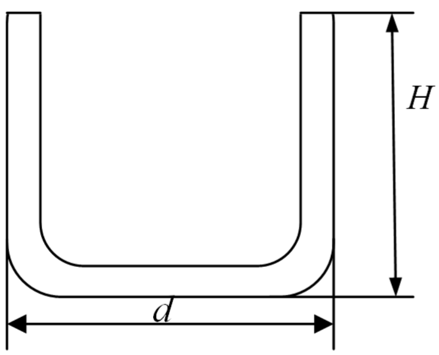

Fig. 4. Scheme of the sample prepared for the stamping process

Table 6

Impact dimensions of the samples obtained in the stamping process

Welding process and materials	Micro-jet gases	Outer diameter d [mm]	Outer high H [mm]	Width of the wall [mm]
S235JR – MAG welding	without cooling	57.67	48.00	8.44
S235JR – MAG welding with MJC	He	57.65	48.03	8.44
S235JR – MAG welding with MJC	N_2	57.68	47.99	8.43
S355J2G3 – MAG welding	without cooling	57.66	48.01	8.44
S355J2G3 – MAG welding with MJC	He	57.68	47.99	8.45
S235JR – MAG welding with MJC	N_2	57.65	48.03	8.44
S355J2G3 with S235JR –– MAG welding	without cooling	57.66	48.02	8.43
S355J2G3 with S235JR – MAG welding with MJC	He	57.67	48.01	8.46
S355J2G3 with S235JR – with MJC	N_2	57.65	48.03	8.44

The width of the wall is uniform along the whole perimeter. The widths of the zone of the weld material and the basic material are the same. The inner and outer surfaces of the walls and bottom are smooth.

It can be easily observed where the weld is in the cylindrical vessel. The surface of the joint is very plain and lighter that the rest of the sample. At the inner and outer surfaces of the sample, we can observe an increase in weld width. The joint is the narrowest at the top edge and it is the widest at the bottom of the sample. This confirms the material plastic flow during the stamping process. The zone of the sample near the top edge is compressed in the peripheral direction and stretched at the bottom.

Therefore, it is clear that the process of micro-jet cooling after MAG welding is crucial for preparing samples for the stamping process. The lack of material in the joint zone at the top edge was clearly visible. This is due to different plastic properties in the parent material and in the joint. The deviations from the coplanarity are presented in Tab. 7.

On analyzing the average degree of deviation measured on the cylindrical vessel (average of 3 measurements in each case), it can be clearly observed that the best plastic properties can be observed in a joint made using helium MJC (the smallest deviation value).

The roughness of the workpiece surface was examined. Any microcracks were observed on samples subjected to micro-jet cooling during welding. However, the samples obtained by welding without rapid cooling or with micro-jet cooling with nitrogen rarely showed microcracks.

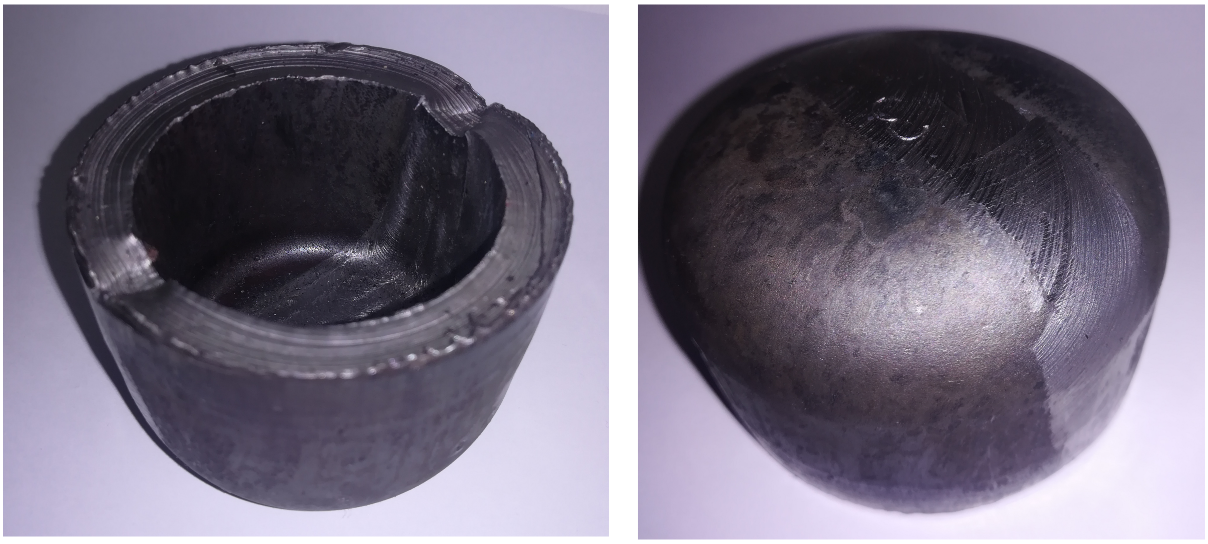

Fig. 5. One of the obtained cylindrical vessels from the inside and outside. Stamping of weld with MJC

Table 7

Deviations from coplanarity in the cylindrical vessel after stamping

Micro-jet gases	Average deviations from the coplanarities *d* [mm]
-	5.13
He	4.34
N_2	4.78

Due to the fact that helium micro-jet cooling yielded the best results, the hardness of the joint was checked before and after the stamping process. Only the root side of the weld made using a helium micro-jet cooling was analyzed. The last tests were carried out to analyze the hardness HV of the joints on the root side before and after stamping. The test results (average of 3 measurements) are presented in Tab. 8.

Table 8

Hardness HV of weld (root side) after welding with helium MJC

Welding materials	Harness HV before stamping	Harness HV After stamping
S235JR	195	213
S355J2G3	181	197
Mixed joint (S235JR with S355J2G3)	192	209

It is possible to deduce that after the stamping process, the hardness increases slightly. This is related to the strengthening of the material after plastic processing, which is stamping. It is also related to a slight increase in the yield point. The increase in hardness after pressing is described in literature [14]. Thus, the research results are not of concern.

4. CONCLUSION

Heavily loaded chassis components for trucks could be produced using the combined processes of welding and stamping. It is much easier to prepare such elements by primary welding and then by stamping, but generally welds have worse plastic properties than the base material. The results of the research confirmed that the application of a modified technological process for welding heavily loaded chassis components could lead to an increase in the plastic properties of the joint, which was confirmed by the impact tests and the stamping result. The metallographic microstructure of the joint was favorable due to the use of micro-jet cooling. Acicular ferrite and MAC phases were carefully analyzed and estimated for all deposits. The innovative MJC technology was also recognized successfully for low-alloy mixed welding.

In this paper, MJC technology was precisely described for two micro-jet gases: helium and nitrogen. On the basis of the investigation, it was found that MJC technology could be an important complement in welding. An important aim of this study was to check the impact toughness and ability of stamping of welds after He micro-jet cooling. The stamping test was very favorable when helium micro-jet cooling was used in the MAG welding of heavily loaded chassis components.

Final conclusions:

a) MJC could be treated as an important element of MAG welding for heavily loaded chassis components,
b) MJC after welding can lead to a significant percentage of acicular ferrite,
c) helium could be treated as a proper micro-jet gas,
d) nitrogen as a micro-jet gas affects the nitrogen content in WMD,
e) the process of welding with MJC may be applied for samples that are to be subjected to the stamping process,
f) the material parameters related to plastic deformations are not significantly changed during welding with micro-jet cooling,
g) the stamping test was successful, and no defects and non-conformities were observed both after welding and after the stamping process and
h) deviations from coplanar-ness were the smallest as a result of pressing plates welded with helium micro-jet cooling.

Research will be continued to find the range of welding and cooling process parameters to obtain the material with characteristics required in plastic deformations.

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