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LASER WELDING WITH MICRO-JET COOLING FOR TRUCK FRAME WELDING

Summary. The aim of this paper is to analyse the mechanical properties of the weld steel structure of car body truck frames after laser welding. The best welding conditions involve the use of proper materials and alloy elements in steel and filler materials, in addition to welding technology, state of stress and temperature of exploitation. We present for the first time the properties of steel track structures after laser welding with micro-jet cooling. Therefore, good selection of both welding parameters and micro-jet cooling parameters is very important to achieve a proper steel structure. In this study, the metallographic structure, tensile results and impact toughness of welded joints have been analysed in terms of welding parameters.

1. INTRODUCTION

Truck during exploitation is subjected to considerable dynamic loads. These are a result of driving on uneven surfaces, sharp curves and hard braking. Frame vehicles have a major impact on the traffic safety of the vehicle. The safety and durability of welded frames in vehicles largely depends first of all on the metallographic structure and the chemical composition of the material [1, 2]. Especially the metallographic structure has an influence on the impact toughness of the structure and its tensile and fatigue strength [3, 4]. New welding techniques and the influence of alloy elements on automotive materials are still being tested [5, 6]. Some are used for car body and lorry frames [8-9]. In the frame of truck vehicles, in addition to major impulse forces during exploitation, there are much smaller stresses, but very often repeated. Such forces may cause fatigue cracks [10-11]. This type of damage is considered to be common and the transition welded frame may not be safe for operation (Fig. 1). There are known cases of damage to the framework of trucks because of fatigue cracking [12].

Welded steel frames are still one of the most frequently encountered structures in trucks [13]. The properties of steel welded structures depend on many factors such as welding technology, filler materials and state of stress. The chemical composition of the weld metal deposit is a very important factor influencing the properties of weld metal deposit (WMD) [7-9]. Some alloy elements, especially nickel (in range 1 - 3%) or molybdenum (in range 0.2 - 0.6%), and oxygen (in range 300-500 ppm) could be considered elements that increase impact toughness. Metallographic

structures of weld metal deposit with the composition 0.08% C, 0.8% Mn, 400 ppm O and 2% Ni or 0.4% Mo could be considered optimal because it corresponds with a high percentage of acicular ferrite AF (until 55%) that corresponds with the high-impact toughness of welds [12-13].



Fig. 1. Typical fatigue cracking in trucks' vehicle frame

The above-mentioned composition could be very beneficial because of the low percentage of MAC phases (self-tempered martensite, retained austenite, carbide), which have a negative influence on impact toughness.

For a long time, researchers have attempted to increase the percentage of AF in weld above 55%, but without much success. The role of non-metallic inclusions during austenitic conversion has been studied extensively; nevertheless, the value of AF could not be increased beyond 55% in WMD. New micro-jet cooling technology [14,15] could be considered a new means to solve this problem. This paper describes the influence of artificially increased amounts of acicular ferrite on WMD (even above 65%) using micro-jet cooling with various parameters of the process. The process was tested with various parameters. Various process parameters were studied such as the diameter of the micro-jet, the micro-jet gas pressure and the type of gas for micro-jet cooling [15]. In the last 5 years, there have been significant studies both on welding and micro-jet cooling, but only after MIG/MAG welding [15]. The influence of processes such as laser welding and micro-jet cooling was not tested before.

2. EXPERIMENTAL PROCEDURE

The weld metal deposit was prepared by laser welding with micro-jet cooling with various gases (argon, helium and nitrogen). To obtain high amounts of acicular ferrite in weld, a micro-jet injector was installed just after welding the laser head. The main parameters of micro-jet cooling were varied slightly as follows:

- the cooling stream diameter was changed twice (50 μm and 60 μm),
- the micro-jet gas pressure was also changed twice (0.5 MPa and 0.6 MPa),
- micro-jet gases were substituted (Ar, He and N₂).

The basic material of research was S355J2G3 steel (which is the typical material for truck frames and car bodies). Various welds of standard laser welding were compared with and without innovative micro-jet cooling technology. A typical weld metal deposit had a fairly similar chemical composition in all tested cases (table 1). The main data on the parameters of welding are shown in table 1.

Various micro-jet parameters had some influence on intensive cooling conditions, but did not have a greater influence on the chemical WMD composition (except nitrogen in WMD).

The metallographic structure of WMD was assessed after chemical analyses of WMD (with various amounts of nitrogen). Acicular ferrite (AF) in terms of the amount of nitrogen in WMD was analysed precisely. In all tested cases, MAC phases (self-tempered martensite, retained austenite, carbide) were also observed. The thickness of the welded sheet for the impact toughness test was 18 mm.

3. EXPERIMENTAL PROCEDURE

The weld metal was obtained after laser welding with micro-jet cooling. The parameters of this process are presented in Table 1.

Table 1
Parameters of the welding process

Parameter	value
Laser power	2,2, 2.2 kW
Welding speed	1.2 m/min
Diameter of the beam spot	200 μm
Focal distance	200 mm
Micro-jet gases	Ar, N ₂ , He
Micro-jet gas pressure	0.5 or 0.6 MPa
Micro-jet diameter	50 or 60 μm

Standard laser welding was mainly tested and compared with micro-jet technology with various micro-jet gases. A typical weld metal deposit had a fairly similar chemical composition in all tested cases, except the amount of nitrogen (Table 2).

Table 2
Chemical composition of WMD after welding

Element	Amount
C	0.07%
Mn	0.7%
Si	0.42%
P	0.012%
S	0.013%
O	370 ppm
N	50-70 ppm

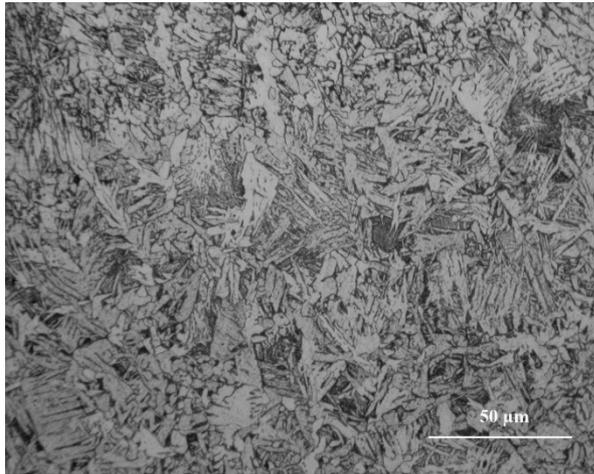
Examples of the results of the metallographic structure analysis are shown in Table 3.

From table 3 it is clear that laser welding with micro-jet cooling could be a very good option. Only argon or helium should be used for micro-jet cooling after laser welding. The amount of acicular ferrite in WMD after simple laser welding without micro-jet cooling was only 45%. The amount of acicular ferrite in WMD after laser welding with nitrogen micro-jet cooling was only 35%. It was also found that micro-jet gas pressure after laser welding with argon or helium micro-jet cooling should be 0.6 MPa and the stream diameter of micro-jet cooling gas should always be 50 μm . Acicular ferrite with a percentage above 60% could be obtained only after micro-jet cooling by helium and 70% after micro-jet cooling by argon (shown in fig. 2).

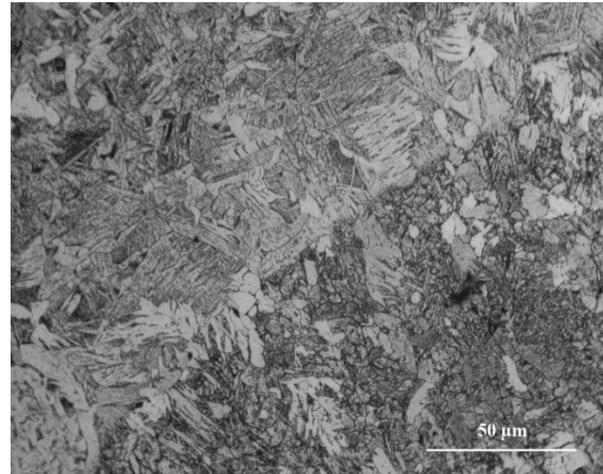
Table 3

Acicular ferrite and MAC phases in WMD after laser welding
with various micro-jet parameters

Micro-jet gas	Micro-jet gas pressure [MPa]	steam diameter of micro-jet gas [μm]	Acicular ferrite [%]	MAC phases, [%]
-	-	-	45	3
Ar	0.5	50	68	2
Ar	0.5	60	69	2
Ar	0.6	50	71	2
Ar	0.6	60	67	2
N ₂	0.5	50	37	3
N ₂	0.5	60	33	3
N ₂	0.6	50	34	3
N ₂	0.6	60	31	3
He	0.5	50	60	2
He	0.5	60	62	2
He	0.6	50	65	2
He	0.6	60	58	2



WMD after He micro-jet cooling (65% AF)



without micro-jet cooling: AF (45%) WMD

Fig. 2. Acicular ferrite in various deposits

It is clear that impact toughness at negative temperatures of the weld metal deposit is affected by the kind of micro-jet gas mixture of the cooling injector. Only argon and helium were good choices. Nitrogen is not recommended as a micro-jet gas for truck welding. Weld metal deposits obtained after welding with argon or helium micro-jet cooling have high fourth impact toughness class (minimum 47 J at $-40\text{ }^{\circ}\text{C}$).

The impact toughness of the weld does not correspond exactly with the impact of the joint. Another structure has an 18 mm thick joint (which is recommended in impact tests) and another structure may have welded components of lower thickness. The impact toughness depends on the content of ferrite AF in the weld; thus, it was decided to analyse the structure of the welded frame elements with various thicknesses of the joint. The results of laser welding without micro-jet cooling are shown in Table 5.

Table 4
Impact toughness for MIG welding with various micro-jet gases

Micro-jet gas	Temp. [°C]	Impact toughness [KV, J]
without cooling	- 40	below 47
Ar	- 40	62
He	- 40	51
N ₂	- 40	below 47
without cooling	0	53
Ar	0	75
He	0	61
N ₂	0	below 47
without cooling	+20	175
Ar	+20	197
He	+20	191
N ₂	+20	166

Table 5

Acicular ferrite in WMD after laser welding after micro-jet argon cooling

Sheet thickness, mm	Amount of acicular ferrite, %	estimated impact toughness (at 0°C), [KV, J]	estimated impact toughness (-40°C), [KV, J]
6	38	below 47	below 47
10	40	above 47	below 47
14	43	above 47	below 47

It is clear that the content of acicular ferrite decreases for ever thinner sheets used for the frame structure. This corresponds with the estimated impact toughness of the joint (impact toughness is estimated as no such tests are performed for thin joints). The results of laser welding with helium micro-jet cooling are shown in Table 5. We determined the content of acicular ferrite after laser welding with micro-jet cooling. Only the effects of helium and argon as micro-jet gases were considered. Nitrogen as a micro-jet gas was found to be unfavourable.

Table 6

Acicular ferrite in WMD after laser welding after micro-jet helium cooling

Sheet thickness, mm	Amount of acicular ferrite, %	estimated impact toughness (at 0°C), [KV, J]	estimated impact toughness (-40°C), [KV, J]
6	52	above 47	above 47
10	58	above 47	above 47
14	62	above 47	above 47

It is clear that also in this case, the content of acicular ferrite decreases in thinner sheets used for frame structures. This corresponds with the estimated impact toughness of the joint (impact toughness is estimated as no such tests are performed for thin joints). Weld metal deposits obtained after welding with helium micro-jet cooling should have high fourth impact toughness class (minimum 47 J at temperature – 40 °C).

Table 7

Acicular ferrite in WMD after laser welding after micro-jet helium cooling

Sheet thickness, mm	Amount of acicular ferrite, %	estimated impact toughness (at 0), [KV, J]	estimated impact toughness (-40°C), [KV, J]
6	52	above 47	above 47
10	58	above 47	above 47
14	62	above 47	above 47

It is also clear that in the last tested case, the content of acicular ferrite decreases in thinner sheets used for frame structures. This corresponds with the estimated impact toughness of the joint (impact toughness is estimated as no such tests are performed for thin joints). Weld metal deposits obtained after welding with argon micro-jet cooling should have high fourth impact toughness class (minimum 47 J at -40 °C).

The next part of the research focused on determination of tensile strength. The results are shown in Table 8.

Table 8

Impact toughness for MIG welding with various micro-jet gases

Micro-jet gas	Yield strength, MPa	Tensile strength, MPa
without cooling	322	491
Ar	315	498
He	325	499
N ₂	336	507

It was observed that micro-jet cooling exerted no effects on strength. Slightly higher strength was observed for the helium-filled or the helium micro-jet connector. Helium is considered the most efficient gas for cooling metal welds; nitrogen in turn strengthens the weld metal deposit (even trace amounts of nitrides in the joint appear). A minimum increase in tensile strength after laser welding with micro-jet cooling has no effect on the interpretation of the previous results. The most important welding test is the impact toughness of the joint and this is the most advantageous when after laser for the frame is used micro-jet argon cooling.

The last part of the research focused on deflection tests of a long structure (in this case 10 m in length). The sheet thickness used for this truck frame simulator was 10 mm. The results are shown in Table 9.

Table 9

Deflection of (10 m) long structure after MAG welding with micro-jet cooling

Micro-jet gas	Deflection, mm
-	55
Ar	53
He	47
N ₂	44

It is possible to deduce that deflection of the structure is apparently affected by micro-jet cooling. In this case, the choice of micro-jet gas in the cooling injector is less important. Also, in this case, deflection of the structure is similar, but can be considered a very good choice for laser welding.

4. CONCLUSIONS

For the first time in the technical literature, the possibility of laser welding of truck frames using micro-jet cooling was analysed. We sought to determine the content of acicular ferrite in the welded joint in terms of micro-jet cooling parameters. The selection of micro-jet gas plays a major role in this process. The effects of helium, argon and nitrogen on micro-jet cooling process were studied. Argon and helium increase the ferrite AF content, which translates into very good plastic properties of the joint. A high acicular ferrite content could not be achieved in other known welding processes. A high amount of acicular ferrite translates into high impact toughness at negative temperatures. Nitrogen is not suitable for use as a micro-jet gas. It decreases the acicular ferrite content and simultaneously reduces the impact toughness of the weld structure. Nitrogen cannot be used as a micro-jet gas for laser welding of vehicle components. To determine the mechanical properties of a welded truck frame using micro-jet cooling, tensile tests were performed. Both yield strengths and tensile strengths in all tests were comparable (after laser welding with and without micro-jet cooling). We also determined the deflection of the simulated frame in all the cases investigated (without cooling micro-jet and cooling with the gases tested: nitrogen, argon, helium). As in the assessment of tensile strength, it was observed that the deflection in all the examined cases was similar.

The influence of processes such as laser welding and micro-jet cooling was tested with success. It was observed that argon or helium micro-jet cooling influenced laser welding of car body structures. It is possible to obtain much higher amounts of acicular ferrite and better impact toughness of welds. The preliminary results show the validity of theoretical assumptions and this technology can be applied in the automotive industry.

On the basis of the investigations, the following conclusions can be drawn:

- micro-jet-cooling is an important element of the laser welding process,
- micro-jet-cooling after welding can increase the amount of acicular ferrite, the most beneficial phase in low alloy steel weld metal deposit,
- a high amount of acicular ferrite can yield, respectively, good impact toughness properties,
- using micro-jet after welding, the metallographic structure can be altered (percentage of acicular ferrite and MAC phases),
- only argon or helium should be used for micro-jet cooling after laser welding,
- tensile strength and deflection in all tested cases (laser welding with and without micro-jet cooling) were similar,
- nitrogen is not suitable for use in micro-jet cooling,
- the type of gas micro-jet used is the most important parameter of the process.

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