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THE CHARACTERISTICS OF WELDED JOINTS OF STAINLESS STEEL FOR AIR CONDITIONING APPLICATION

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S u m m a r y

In the paper the results of metallographic examination of welded joints for car air–conditioning unit are presented. The European directives 2006/40/EC on the greenhouse gasses elimination demand to stop using traditional refrigerant and to change it to R744 medium in air conditioning installation. The R744 (CO_2) refrigerant is environmental friendly medium if compared with standard solution such as R12, R134a or R1234yf and safer for passengers than R1234yf. The non-standard thermodynamic parameters of the R744 which translate into high pressure and high temperature require specific material to develop the shape and to specify the technology of manufacturing for the particular elements of the conduits and moreover the technologies of joining for the whole structure, which would meet the exploitation requirements of the new unit. To produce the test welded joints of stainless steels three different joining technologies were applied: laser welding, plasma welding as well as high speed friction welding. The results indicated that laser and plasma technologies guaranty the proper quality of welded joints and can be used for the air conditioning application in automotive industry.

Keywords: air-conditioning, laser welding, plasma welding, high speed friction welding

Charakterystyka połączeń spawanych ze stali odpornej na korozje w systemach klimatyzacji

S t r e s z c z e n i e

W pracy przedstawiono analizę wyników badań mikroskopowych połączeń spawanych stosowanych w samochodowych systemach klimatyzacji. Europejska dyrektywa 2006/40/WE dotycząca gazów cieplarnianych wymaga ograniczenia dotychczas używanych tradycyjnych czynników chłodniczych. Zaleca stosowanie czynnika R744 w instalacjach klimatyzacji. Nowy czynnik chłodniczy R744 (CO_2) jest mniej niebezpieczny dla środowiska i bezpieczniejszy dla pasażerów w porównaniu z tradycyjnymi, m.in.: R12, R134a lub R1234yf niż R1234yf. Niestandardowe parametry termodynamiczne eksploatacji czynnika R744 – duże ciśnienie i wysoka temperatura wymagają wprowadzenia nowych materiałów, zmiany konstrukcji samych systemów i opracowania technologii poszczególnych jej elementów – przewodów. Również opracowania technologii łączenia elementów instalacji całej konstrukcji, spełniającej wymagania eksploatacyjne nowego systemu klimatyzacji. Próbne połączenia spawane elementów ze stali nierdzewnej wykonano z zastosowaniem trzech technologii: spawanie laserowe i mikroplazmowe oraz zgrzewanie tarciowe. Analiza wyników prowadzonych badań wykazała, że

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technologie laserowe i mikroplazmowe gwarantują odpowiednią jakość połączeń spawanych. Mogą być stosowane w systemach klimatyzacji w przemyśle motoryzacyjnym.

Słowa kluczowe: klimatyzacja, spawanie wiązką laserową, spawanie mikroplazmowe, zgrzewanie tarciowe szybkoobrotowe

Introduction

Car air conditioning has become more and more popular. Nowadays, it is difficult to buy a new car without air cooling system. The air conditioning system ensures a thermal comfort for passengers, but also contributes to the defogging of windows and thus increases the active safety factor. Automobile air conditioning equipment is markedly different from the air conditioning facilities found in buildings since, in contrast to the stable conditions of a building, conditions inside an automobile vary markedly in both time and space [1].

When a car is driven or parked in the sun, heat enters the vehicle from many sources (Fig. 1). These sources include: ambient air, sunlight, engine heat, road heat, transmission as well as exhaust heat. All of these and other miscellaneous heat sources, increase the air temperature within the vehicle. In a high ambient temperature situation, (e.g. on a 37°C day), the interior of a vehicle left standing in the sun with windows closed could reach 65-70°C [2].

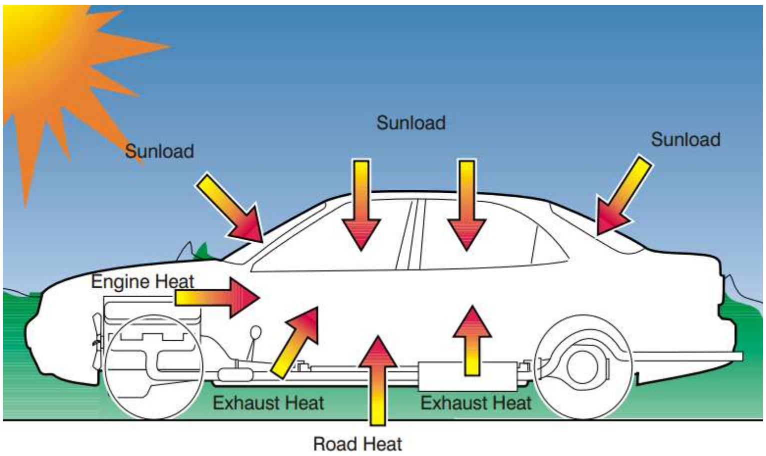

Fig. 1. Sources caused the increase of the temperature in the car [2]

The refrigerant commonly used in car air conditioning (CAC) systems is tetrafluoroethane, R134a for short. R134a has a high global warming potential (GWP), 1,300 times higher – according to more recent calculations by the Intergovernmental Panel on Climate Change (IPCC), even 1430 times higher – than that of CO_2. A comparison of most popular refrigerants are given n Table 1.

Table 1. Comparison of refrigerants [3, 4]

Comercial name	**R12**	**R134a**	**R1234yf**	**R744**
Chemical name	Dihlorodifluoro metan	Tetra Fluoro Etan	tetrafluoropropane	hydrocarbon
Ozone depleting	1,0	0.03	0	0
Global worming potential	10600	1430	4	1
Boiling point	–29.6	–26.3	–29.0	–78.4

A car equipped with air conditioning produces additional emissions corresponding to 7 grams of CO_2 per driven kilometer by the continuous release of R134a from the system. As a result, CAC systems have been veritable climate offenders up to the present. Car air conditioning systems are the single most important source of fluorinated greenhouse gases, mainly due to high emissions during their operation and their large numbers. More than 400 million vehicles worldwide are equipped with CACs. The climate experts of the IPCC expect that there were nearly 1 billion air-conditioned vehicles by 2015. In 2015 alone, these was release refrigerant to the atmosphere on a scale of at least 270 million tonnes of CO_2 equivalent, contributing to climate change. In Germany, almost 2300 tonnes of the fluorinated refrigerant R134a were emitted to the atmosphere in 2006 alone. This is equivalent to almost 3 million tonnes of CO_2, which is as much carbon dioxide as is emitted via the exhaust gas pipe of 1.7 million small-sized vehicles each driving 15000 kilometres per year [3, 4].

The European directives 2006/40/EC [5] on the greenhouse gasses elimination demand to stop using traditional refrigerant and to change it to R744 medium in air conditioning installation. The R744 (CO_2) refrigerant is environmental friendly medium if compared with standard solution such as R12, R134a or R1234yf and safer for passengers than R1234yf.

The non-standard thermodynamic parameters of the R744 which translate into high pressure and high temperature required specific material to develop the shape and to specify the technology of manufacturing for the particular elements of the conduits and moreover the technologies of joining for the whole structure, which would meet the exploitation requirements of the new unit. In the paper the results of metallographic examination of welded joints for CO_2 air–conditioning units are presented.

Experimental details

To produce the test welded joints of stainless steels three different joining technologies were applied: laser welding, plasma welding as well as high speed friction welding. The components of High Pressure High Temperature line (HP HAT**)** are shown in Fig. 2.

a) b)

Fig. 2. The components of high pressure high temperature line: a) nipple, b) corrugated hose

AISI 406 (nipple) and AISI 316L (corrugated hose) steels were chosen for the present study. Their chemical composition are shown in Table 2. All specimens were welded by pulsed laser TruPulse 103 (Fig. 3a), plasma MSP-51 machine (Fig. 3b) as well as Harm&Wende high-speed friction welding machine RSM 400 (Fig. 3c) located at Instytut Spawalnictwa (Institute of Welding) in Gliwice. Microstructure was observed by an Eclipse MA 200 (Nikon) light microscope (LM) as well as scanning electron microscope (SEM) Hitachi SU 70. The samples to microscopy observations were polished mechanically with the application of Struers equipment and technique.

Table 2. Chemical composition of AISI 304 and AISI 316L steels

Steel	**Element cartents, mas %**						
	C	**Mn**	**Cr**	**Ni**	**P**	**S**	**Si**
AISI304	0.08	2.0	18.0-20.0	8.0-10.5	0.045	0.03	1.0
AISI316L	0.03	2.0	16.0-18.0	10.0-14.0	0.045	0.03	1.0

Results and discussion

The microstructures of the investigated AISI 304 and AISI 316L steels in their as-delivered state are presented in Figs. 4 and 5. Steels displayed an austenitic structure with a twins.

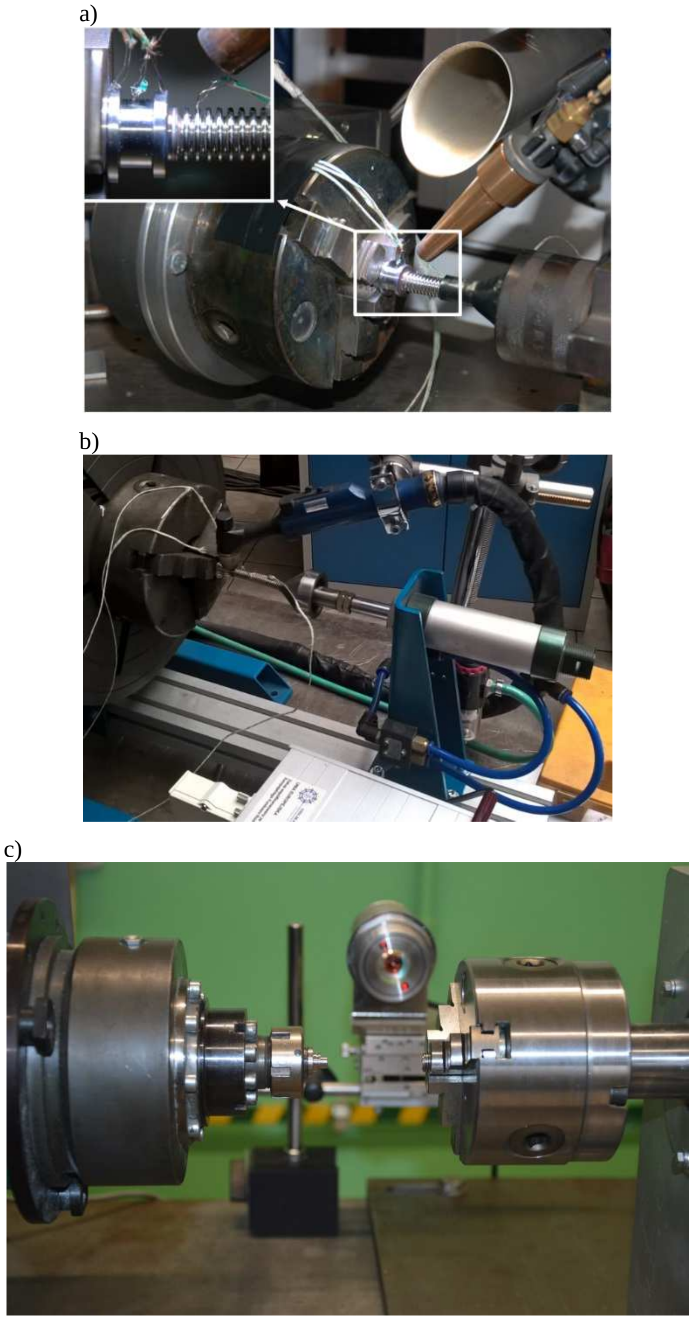

Fig. 3. Welding setups: a) laser welding, b) plasma welding, c) high speed rotational friction welding

a) b)

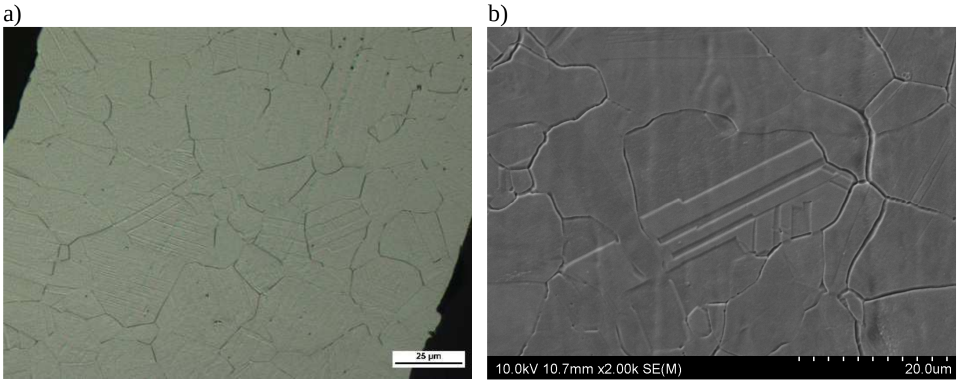

Fig. 4. The microstructure of AISIS 304 base metal used in the study: a) light microscope, b) SEM

a) b)

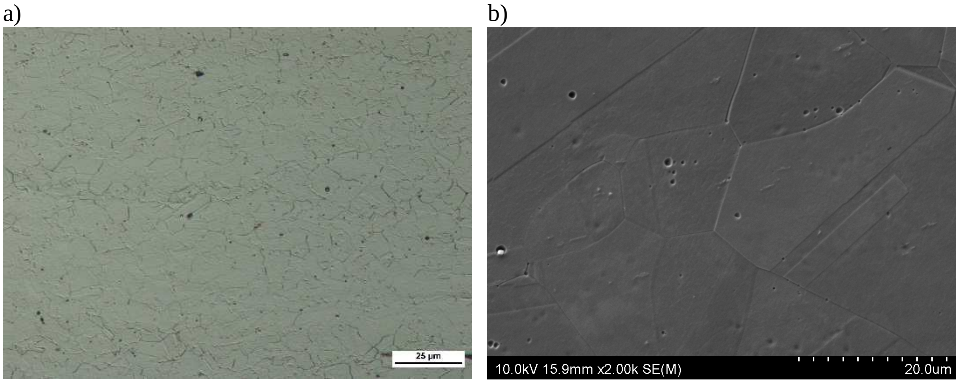

Fig. 5. The microstructure of AISIS 316L base metal used in the study: a) light microscope, b) SEM

The macrostructure of laser beam welded joints are shown in Fig. 6. It can be seen that the fusion zones depend on welding parameters. Decrease in the beam diameter caused the increase in the penetration depth and decrease in the width of the welds. It is because decreasing the beam diameter at the constant power increases the power density.

Furthermore, SEM micrograph (Fig. 7) across the fusion boundary shows the heat-affected zone (HAZ) and a sensitized region along the fusion line at the fusion zone. The HAZ adjacent to the fusion line represents base metal heated above the A3 temperature during the weld thermal cycle, and is characterized by austenite grains surrounded by grain boundary martensite. Figure 7 also shows that the amount of martensite present in the microstructures is inadequate to control the grain coarsening in HAZ [6].

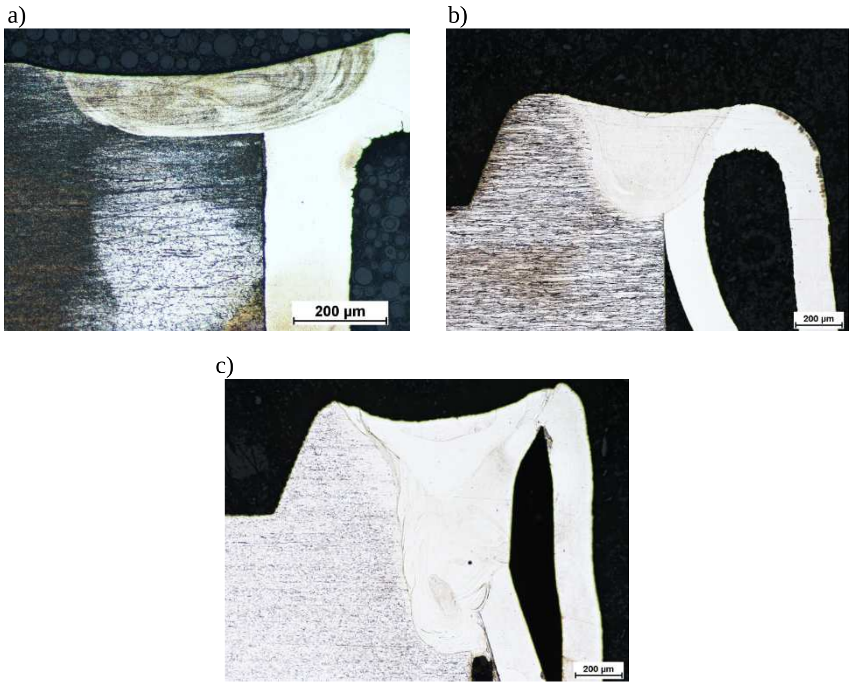

Fig. 6. The macrostructure of the laser beam welded joints at different beam diameter:
a) 0.8 mm, b) 0.6 mm, c) 0.4 mm

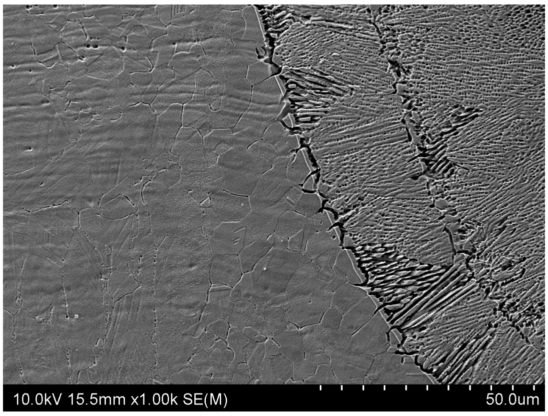

Fig. 7. Microstructure of laser welded joint – AISIS 316L steel

Therefore, despite the partial solid-state phase transformation on cooling, the HAZ is, in general, characterized by a coarse grain size. On the other hand, narrow (up to few μm) dark-sensitized zone along the fusion line has been formed probably due to the precipitation of grain boundary carbides. The region adjacent to the fusion line of the fusion zone is subjected to the initiation of primary ferrite solidification and dendritic growth from the liquid metal during cooling. Therefore, prior to complete solidification, interdendritic liquid became enriched with alloying elements (mostly carbon, nitrogen, nickel, and chromium) due to high alloy segregation (rejection of C, N, and Ni from δ-phase to surrounding liquid). Because of the higher concentration of austenitic stabilizing elements, remaining liquid solidified in γ-phase and δ/δ interfaces became the potential site for carbide and nitride precipitations (mostly $M_{23}C_6$ and MX type) [6]

For the plasma welded joints similar situation can be observed. The macrostructure and microstructure of a welded joint is shown in Figures 8a and 8b, respectively. However, the longer cooling time $t_{8/5}$ caused that the HAZ is wider.

a) b)

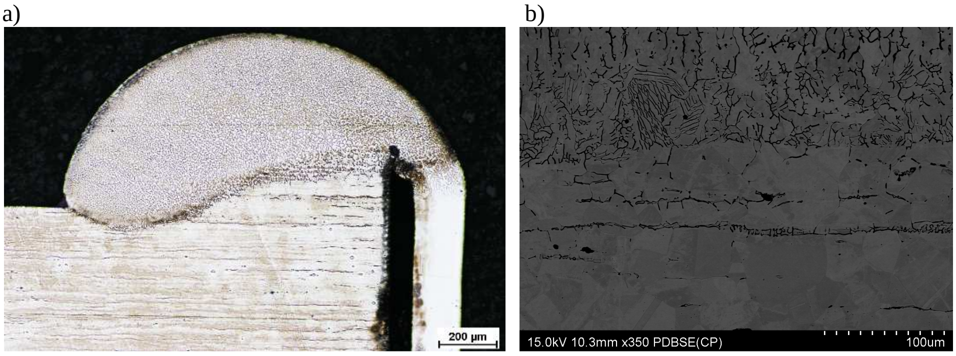

Fig. 8. The macrostructure and microstructure of plasma arc welded joint

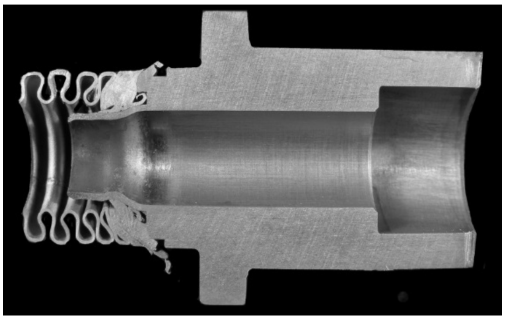

Fig. 9. Macrostructure of high speed friction welded joint

The preliminary investigation of high speed friction welded joints has revealed that at the standard shapes of the nipple and corrugated hose it is not possible to achieve the proper quality of welded joint. The macrostructure of welded joint is shown in Fig. 9. As can be seen a corrugated hose undergoes intensive plastic deformation. Simultaneously, material of the nipple undergoes heating up only. This is because of the difference between thickness of corrugated hose and nipple. The next investigation will be carried out. The main task will be modifying the shape of the nipple.

Summary

This paper describes the influence of the selected welding process on the macrostructure and microstructure of welded joints of AISI 304 and AISI 316L steels. The results of this research are summarized as follows:

- the welding process have dominant influence on geometry and macrostructure of welded joints,
- the proper quality of welded joints for laser as well as plasma arc welding can be achieved,
- the high speed friction welding fails to guarantee the proper quality of welded joint, however the technology will be developed,
- HAZ adjacent to the fusion line in laser and plasma welding is characterized by coarse grain size.

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