Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 119 **2023**

p-ISBN:: 0209-3324

e-ISBN:: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2023.119.15

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Szczucka-Lasota, B., Węgrzyn, T., Cybulko, P. Application of Fe_3Al intermetallic phase filler metal in valve seating face hard facing. *Scientific Journal of Silesian University of Technology. Series Transport*. 2023, **119**, 257-265. ISSN: 0209-3324.
DOI: https://doi.org/10.20858/sjsutst.2023.119.15.

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APPLICATION OF FE_3AL INTERMETALLIC PHASE FILLER METAL IN VALVE SEATING FACE HARD FACING

Summary. The exhaust valve seat face is a surface that degrades slowly as a result of mechanical and thermal stresses. There is extensive research on new materials for valves and for the improvement of valve production technology. This paper discusses the method of obtaining a filler metal made of Fe_3Al intermetallic phase and the method of TIG hard-facing on a valve seating face made of H9S2 steel, evaluating the effects of essential hard-facing parameters. The resulting hard-facing build up was assessed in terms of quality using industrial radiography testing (RT).

Keywords: engine, valve, intermetallic phase

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1. INTRODUCTION AND STATEMENT OF THE RESEACH PROBLEM FOR THE AUTOMOTIVE INDUSTUSTRY

The exhaust valve seat face is a surface that undergoes a slow process of degradation. The valves are made of heat- and creep-resistant steels. The most common valve steel grades are H9S2 or H10S2M, both having a perlite-martensitic structure. Both grades are mainly used in the automotive industry. They are characterised by high hardness and significant resistance to abrasion. These grades of steel are commonly used for:

- diesel engine exhaust valves;
- exhaust valves of other internal combustion engines;
- inlet valves of internal combustion engines working under heavy loads.

H9S2 steel has a similar composition and properties to H10S2M steel, but the lower molybdenum content results in decreased resistance to oxidation and high-temperature creep at temperatures lower by approximately 50° C. Valves made of H9S2 steel were used in this study. The most important advantages of this steel include:

- Heat resistance against negative effects of gases up to 850° C;
- Creep resistance up to 600° C.

The impact of engine operating conditions such as number of cycles, combustion pressure and temperature on valve face wear were investigated by researchers such as Lewis [1], who demonstrated a relationship between valve abrasive wear and the increase in combustion chamber pressure. At the same time, a decrease in valve seating face wear was observed as the temperature increased. This effect is attributed to a film of metal oxides formed as a result of the exhaust valves coming into contact with high-temperature exhaust gases [1]. Another study reported that the wear of the valve seating face was mainly related to the misalignment of the valve and valve seat and to the resulting abrasive wear that occurred at the contact point [2]. Other studies indicate that the wear process is a complex combination of oxidation, adhesion and abrasive wear processes [3-5]. Today, cobalt alloys, mainly Stellite, are used to strengthen the top layer of the engine valve seating face. Apart from cobalt, these alloys contain up to approx. 32% Cr, up to 14% W and 4% C. Stellites are exceptionally high hard, up to 64 HRC (immediately after casting), but also brittle, show a high abrasion and heat resistance (up to 950°C), and exhibit good corrosion resistance. They are also used in friction couples, e.g. as the top layer of valve seats of internal combustion engines, in gas turbines, aircraft turbines, in the petrochemical industry and in the energy sector [6,7]. Stellite is used to strengthen the surface of the valve seating face, which forms a friction couple with the valve seat. The location of the surface hardening of the valve with Stellite is presented in Figure 1.

Stellite reinforcement of valve seating face surfaces is the most common method of preventing valve face degradation in diesel and petrol engines. In recent years, various industries have shown a growing interest in metal alloys with a base of intermetallic phases (intermetallics) such as those found in the Fe-Al equilibrium phase diagram. This is dictated by demands of designers for construction materials to be able to operate in increasingly variable and aggressive conditions. The Intermetallics are phases of alloys of two or more metals with well-established proportions [9-11]. The Fe_3Al intermetallic phase has a lower density (approx. 6 g/cm^3) compared to the Stellite currently used for valve seating face surfacing (approx. 9 g/cm^3). The difference in specific gravity is due to the high percentage of aluminium (low density) in the Fe_3Al phase [7]. During the operation of the valves, this component is exposed to combustion products of fuel, but also of substances which, under high temperatures, have a degrading effect on the exhaust valve seating face [13-14].

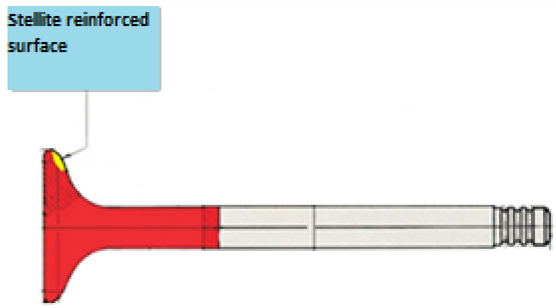


Fig. 1. Location of Stellite reinforcement of the valve seating face [8]

2. OWN RESEARCH

The parent metal was made of H9S2 steel (in accordance with EN: X45CrSi9-3 - 1.4718). The chemical composition of the steel is shown in Table 1.

Tab. 1.

Chemical composition of the parent material

Chemical composition of H9S2 steel, %						
C	Mn	Si	P	S	Cr	Ni
0.43	0.5	2.5	0.021	0.023	9.2	0.5

The intermetallic phase of Fe_3Al served as the filler metal. The chemical composition of the intermetallic filler metal is shown in Table 2.

Tab. 2.

Chemical composition of the filler metal

Chemical composition of the Fe_3Al phase, %		
Fe	Al	Other elements (mainly Zr)
82.2	15.4	2.4

The Fe_3Al intermetallic phase belongs to the group of materials that are difficult to process, and therefore hard to use it as a construction material for components to be used during the hard-facing process. Waterjet cutting technology was used to make the form of the filler rods. Processing materials which need higher kinetic energy of the water stream, an abrasive is added to the water to increase the erosion of the processed material [12]. The cutting process was carried out on a Kimla Streamcut 3030 unit using garnet as the abrasive, with the machine set to parameters shown in Table 3.

Tab. 3

Water jet cutting parameters

Parameter	Value	Unit
Water pressure	345	MPa
Abrasive particle size	0.35	mm
Head movement speed	31	mm/min
Water stream diameter	1.2	mm

High-pressure water and abrasive jet cutting was used to create filler rods with cross-sections of 1.3 mm × 1.3 mm and 1.4 mm × 1.4 mm. Such dimensions of the filler metal were chosen due to the availability of conventional steel filler rods of identical dimensions that are commonly used in TIG hard-facing. The method of creating 1.3 mm × 1.3 mm filler metal is shown in Figure 2.

Fig. 2. Filler metal (rods) prepared for TIG hard-facing (bright areas)

In order to determine the feasibility of using TIG hard-facing to reinforce the top layer of the valve seating face, the filler metal was welded onto the surface of the valve seat face. In the process of TIG welding and TIG hard-facing, there is an important difference in the way the filler metal (rod) is fed. In welding, the filler metal must be fed to the weld pool to obtain sufficient fusion, while in hard-facing the filler metal must be added to the arc to avoid excessive penetration. This paper examines the impart of the most important welding parameters:

- current (60-70 A),
- arc voltage (18-20 V),
- welding speed (70-80 mm/min).

Argon with a flow rate of 8.5 l/min was used as the shielding gas. A size 6 welding nozzle was used to increase the uniformity of the shielding gas outflow and to keep the welding area clean. TIG hard-facing on valve steel was carried out as follows:

- single hard-facing using a tungsten electrode (2.4 mm);
- use of Fe_3Al filler metal, 1.3 mm × 1.3 mm and 1.4 mm × 1.4 mm;
- no preheating of the valve steel;
- the intermetallic filler was fed manually.

Prior to TIG hard-facing, the surface of the seating face was chemically cleaned using acetone. The characteristics of the hard-facing process as a function of the selection of welding parameters are shown in Table 4.

Tab. 4

Selection of TIG hard-facing parameters using Fe_3Al intermetallic phase filler

Used process parameters	Characteristics of the hard-facing process
Current: 60 A **Arc voltage: 18 V** **Welding speed 80 mm/min,** **filler metal: 1.3 mm × 1.3 mm**	Incorrect process parameters. Problems were observed with the formation of a correct weld pool. This was caused by too low welding current during hard-facing.
Current: 64 A **Arc voltage: 19 V** **Welding speed 80 mm/min,** **filler metal: 1.3 mm × 1.3 mm**	Correct process parameters. In the initial phase of the hard-facing, a slight local spill of the filler metal could be observed, related to the formation of the weld pool. No problems were observed with the formation and control of the shape and guidance of the weld pool
Current: 64 A **Arc voltage: 18 V** **Welding speed 90 mm/min,** **filler metal: 1.3 × 1.3 mm**	Correct process parameters. In the initial phase of the hard-facing, a slight local spill of the filler metal could be observed, related to the formation of the weld pool. No other excessive spill on the remaining circumference of the valve seating face was identified. The application of the intermetallic phase was fully controlled.
Current: 68 A **Arc voltage: 19 V** **Welding speed 90 mm/min,** **Filler metal: 1.3 mm × 1.3 mm**	Problems were observed with the formation of a correct weld pool. Issues with the uniform application of the filler metal into the weld pool. This was caused by too high welding current during hard-facing.
Current: 62 A **Arc voltage: 18 V** **Welding speed 80 mm/min,** **filler metal: 1.4 mm × 1.4 mm**	Incorrect process parameters. Problems were observed with the formation of a correct weld pool. This was caused by too low welding current during hard-facing.
Current: 66 A **Arc voltage: 18 V** **Welding speed 80 mm/min,** **filler metal: 1.4 mm × 1.4 mm**	Correct process parameters. In the initial phase of the hard-facing, a slight local spill of the filler metal could be observed, related to the formation of the weld pool. No problems were observed with the formation and control of the shape and guidance of the weld pool
Current: 66 A **Arc voltage: 18 V** **Welding speed 80 mm/min,** **filler metal: 1.4 mm × 1.4 mm**	Correct process parameters. In the initial phase of the hard-facing, a slight local spill of the filler metal could be observed, related to the formation of the weld pool. No other excessive spill on the remaining circumference of the valve seating face was identified. The application of the intermetallic phase was fully controlled.

Current: 70 A **Arc voltage: 18 V** **Welding speed 80 mm/min,** **filler metal: 1.4 mm × 1.4 mm**	Problems were observed with the formation of a correct weld pool. Problems were observed with the uniform application of the filler metal into the weld pool. This was caused by too high welding current during hard-facing.

The information presented in the table indicates that current is the most important welding parameter, having a significant effect on the form of the build-up weld. In the case of the 1.3 mm × 1.3 mm filler metal, it was noted that the current should be set at 64 A, while for a weld with a cross-section of 1.4 mm × 1.4 mm, the current should be set at 66 A. The arc voltage and welding speed in the tested range had no significant effect on the appearance of the weld.

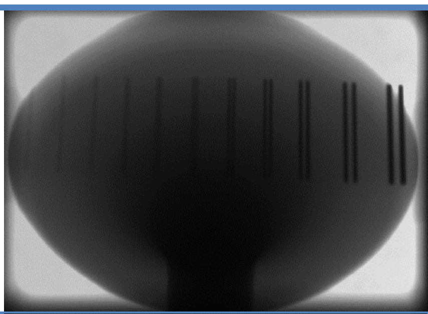
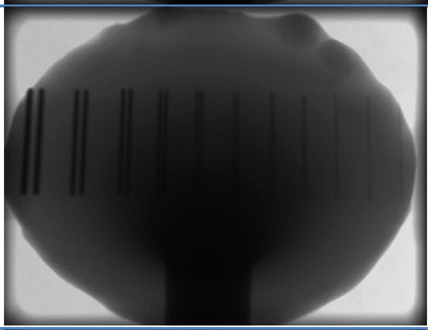
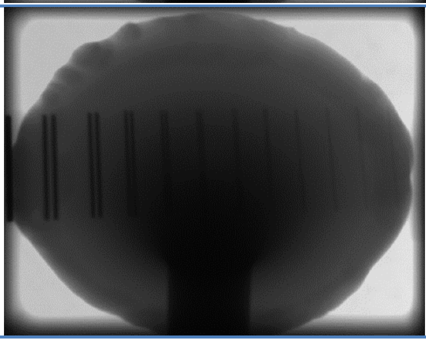
Fig. 3 shows an example of the valve seat face after hard-facing using the most favourable welding parameters (I=64 A).

Fig. 3. Valve seating face after TIG hard-facing, filler metal cross-section: 1.3 mm × 1.3 mm, I= 64 A

It was observed that the surface seating face has the correct form only with the appropriate welding current of I=64 A (filler metal cross-section 1.3 mm × 1.3 mm). It was observed that the surface of the seating face has the correct form only with the appropriate current of I=66 A (filler metal cross-section 1.4 mm × 1.4 mm). In order to analyse the quality of the process, the two obtained hard-facings were subjected to industrial radiography test (RT). These studies make it possible (Table 5) to detect internal, subsurface and surface discontinuities in test objects. RT examinations involve exposing an object to X-rays. The image of the scanned object is recorded on radiographic film. This method is often used to inspect welded joints, among other things. Testing and evaluation of welds was performed in accordance with PN-EN ISO 17635 for non-destructive testing of welds, and in compliance with the general rules for metals according to PN-EN ISO 17636-2 for non-destructive testing of welds. Radiography was conducted in accordance with PN - EN ISO 6520-1 *Welding and allied processes*. Geometric weld inconsistencies in metals were classified using PN- EN ISO 5817 Welding – Fusion-welded joints of steel, nickel, titanium and their alloys.

Tab. 5

Analysis of RT images of a valve hard-faced with Fe_3Al intermetallic phase

Valve appearance / filler metal dimensions [mm]	**RT image**	**Radiographic image interpretation**
Before hard-facing (valve only)		No defects found internally
After hard-facing with 1.4 mm filler metal		No defects found internally
After hard-facing with 1.3 mm filler metal		No defects found internally

The images in Table 5 confirm that the two tested hard-facings made using the Fe_3Al intermetallic phase filler metal do not show any welding imperfections or defects. For quality level B according to PN-EN ISO 5817, the maximum permissible dimension of a single gas bubble is $d \leq 0.2 \cdot a$, but no more than 3 mm. Based on these guidelines, the acceptable bubble size for the test object is 1 mm. The dimensions of the identified discrepancies are below 1 mm. On this basis, it can be concluded that the created hard-facing falls into quality level B.

The final point of the study was to analyse the quality of hard-facing in terms of microstructure. Figure 4 illustrates the structure of the hard-facing welds and the correct fusion at the interface between the steel surface of the valve and the intermetallic build-up.

Analysis of the image indicates fusion is correct, and the weld is free of defects and welding inconsistencies, which is confirmed by the result of the radiographic tests.

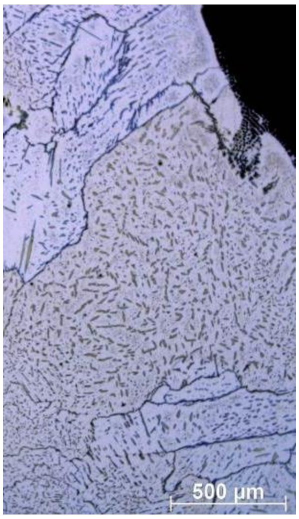


Fig. 4. Microstructure after TIG hard-facing of the valve,
1.3 mm × 1.3 mm filler metal, I= 64 A

3. CONCLUSION

This article presents the possibility of hard-facing steel used for the valve seating face of an internal combustion engine using an intermetallic filler metal. The Stellite reinforcement used to date does not meet the demands presented by developers of modern means of transport. The study has shown that the use of TIG hard-facing at specific process parameters allows the correct fusion of the Fe_3Al intermetallic phase with the valve seating face material made of H9S2 steel. The quality of the weld build-up depends on the cross-sectional dimensions of the filler metal and the welding parameters. This paper examines the combined effects of welding current, arc voltage and welding speed used in hard-facing on the quality and form of the weld build-up. It was found that satisfying results were obtained using a Fe_3Al filler metal in two sizes, 1.3 mm × 1.3 mm and 1.4 mm × 1.4 mm. Proper execution of the hard-facing weld was confirmed by photographic evidence, the results of radiographic tests and microstructure analysis. Based on the conducted research, it can be concluded that the analysed technology valve steel hard-facing with Fe_3Al phase filler metal can be successfully applied in the construction of internal combustion engine valves.

Acknowledgement
The paper is a part of the COST project, CA 18223 and the part of presented research was funded by Silesian University of Technology grant number BK-277/RT1/2021.

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Received 20.11.2022; accepted in revised form 21.02.2023