V. MARUŠIĆ, S. ARAČIĆ, I. SAMARDŽIĆ

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THE INFLUENCE OF THE BASE MATERIAL SURFACE PREPARATION ON THE PROPERTIES OF THERMALLY SPRAYED COATINGS

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Using specimens, a research was conducted to determine the influence of the base material surface preparation for 42CrMo4 on the final coating, prior to actual thermal spraying. During thermal spraying, an Al-Ni-alloy was used as an interlayer before the actual coating with Cr-Mo-Ni. The surface hardness and the hardness distribution across the thickness of the sprayed coating were measured and the structure of respective sprayed coatings was photographed. A comparison of experimental results enabled the identification of the particular material preparation method with an optimal ratio of the satisfactory coating thickness and its hardness.

Key words: thermal spraying, gas flame, surface preparation, hardness, steel 42CrMo4

Istraživanje utjecaja pripreme površine osnovnog materijala na svojstva toplinski naštrcanog sloja. Na uzorcima je istraživan utjecaj kvalitete pripreme površine osnovnog materijala 42CrMo4 prije naštrcavanja na svojstva toplinski plinski naštrcanog sloja. Pri naštrcavanju je kao međusloj korištena legura Al-Ni, dok je za završni sloj korištena legura Cr-Mo-Ni. Izvršena su ispitivanja površinske tvrdoće, toka tvrdoće po debljini naštrcanog sloja, te odgovarajuća snimanja struktura naštrcanih slojeva. Usporedbom rezultata ispitivanja utvrđena je priprema površine osnovnog materijala kod koje se postiže prihvatljiva debljina naštrcanog sloja uz postizanje zadovoljavajućih tvrdoća u naštrcanom sloju.

Ključne riječi: toplinsko naštrcavanje, plinski plamen, priprema površine, tvrdoća, čelik 42CrMo4

INTRODUCTION

Thermal spraying is oftentimes used to repair the flaws or damages on the heavy and complexly shaped shafts and axle trunnions. For such parts, welded facing may cause (macro) deformation due to intensive heat penetration and problems with final machining. It is not a rare case that axles and shafts of 500 to 1000 kg cease to function as required only because of locally concentrated surface cracks and dents with a total loss of material measured in the several tenths of a gram. Prior to spraying, these large parts are machined in the workshops where the conditions often differ and cannot match the laboratory setting. The experimental plan entails several variants of the base material preparation that would then be subjected to thermal spraying of the added material. The aim of the experiment is to use the variations of the surface structure and the quality during the base material preparation, in order to specify the influence of surface parameters on the required final properties of the sprayed coating.

V. Marušić, S. Aračić, I. Samardžić, Faculty of Mechanical Engineering, University of Osijek, Slavonski Brod, Croatia

DAMAGES ON A WAGON AXLE AND ON THE SHAFT OF A SCREW PRESS

In order to determine which base material to investigate, a preliminary screening was carried out [1, 2, 3]. Based on that information and due to its frequent use for shafts and axles, quenched and tempered 42CrMo4 steel was selected as the base material – a specification according to EN 10027-1 [4]. Among other applications, that particular steel is used to manufacture the components of cargo rail wagons and the screw press shafts.

Figure 1. shows an example of damage on the axle of a rail wagon as caused by torsion of the inner ring of the roller bearing. Such damages appear as cracks (surface mechanical damage) of 0,8 mm in depth and 40 to 50 mm in length radially to the wheel axis [1]. The trunnion is 180 mm long, ϕ 120.

The photo in Figure 2. shows the screw press shaft which was damaged after only 2 years in operation. A screw press is basically an endless screw provided with a conical shaft that compresses the pulp as it moves from an inlet to an outlet. The endless screw is enclosed in a body that is provided with a screened surface allowing the excess fluid to be expelled from the pulp. The shaft length is $\approx$ 4500 mm and it has a cascade diameter of ϕ 152 / ϕ

Figure 1. Damaged trunnion of a wagon axle

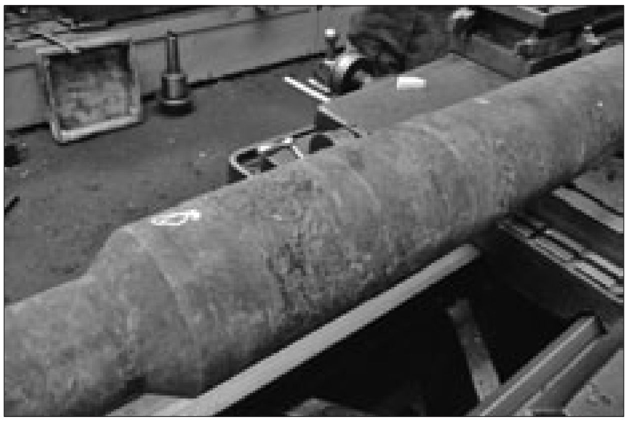


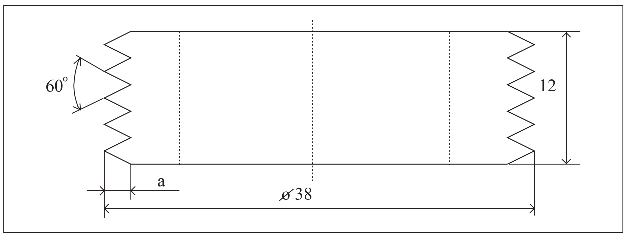
Figure 2. Damaged shaft of the screw press

Table 1. **The chemical composition of base material as determined for the wagon axle, the screw press shaft and the test specimens [1, 2]**

Specification	Chemical composition / %				
	C	Si	Mn	Cr	Mo
Screw press shaft	0,43	0,31	0,82	1,16	0,20
Test specimen	0,43	0,33	0,72	1,05	0,23
Defined for 42CrMo4 as per EN 10027-1	0,38 0,45	max. 0,40	0,60 0,90	0,90 1,20	0,15 0,30

153,8 / ϕ 155 / ϕ 158 / ϕ 160. The damage occurred on the segment ϕ 152 to ϕ 155 and had a length of $\approx$ 1600 mm. Using a comparator, the depth of local damages was measured as reaching up to 2 mm. It must be pointed out that the shaft surface was found greasy due to oil and seed residue particles protruding between the facings of adjacent screw press segments. The hardness of the screw press was measured with a mobile measurement unit and found to be in the range of 200 to 220 HB.

A chemical analysis confirmed that the materials of both the wagon axle and the screw press shaft match that of quenched and tempered 42CrMo4 steel (Table 1). The same table gives the chemical composition data for the specimens (the material had been delivered quenched and tempered and of the measured hardness of 230 HB). The damaged shafts and axles can be repaired using gas flame thermal spraying. Added materials and other parameters that determine the particular technological method must be selected based on the required exploitation conditions for the particular component.



a = 0,25 mm; *a* = 0,50 mm; *a* = 1,00 mm; *a* = 1,25 mm

Figure 3. The appearance and dimensions of specimens 1 – 4, as prepared for spraying by surface cutting

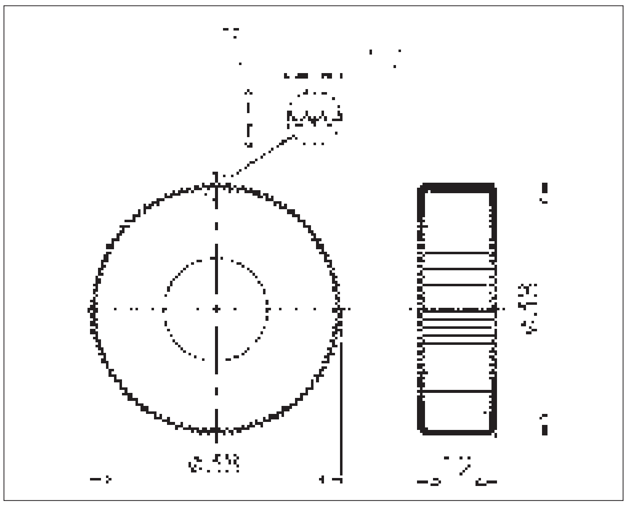


Figure 4. The appearance and dimensions of the specimen No.5, as prepared for spraying by surface knurling

EXPERIMENT PLAN

According to the experiment plan, the respective specimen surfaces (dimensions given in Figure 3 and 4) were prepared as follows:

I – using cutting methods (specimens No. 1; 2; 3 and 4)

II – by means of mechanical knurling (specimen No. 5).

For each of the two types of surface preparation, a total of ten specimens were produced from the same shipment of 42CrMo4 (the base material). Such a selection of the specimen surface structures enables a determination of the influence of various surface preparation methods on the mechanical properties of thermally sprayed coatings.

Two additional materials were used for spraying – an interlayer based on Nickel – Aluminium wire and Chrome – Molybdenum wire for the final coating. The properties of these materials are given in Table 2.

Before spraying, the specimens had been mounted onto a "thorn" bearing (the dimensions are given in Figure 5.a). A set of already sprayed specimens is given in Figure 5.b.

To perform spraying of the additional material, the thorn bearing was fixed into a lathe chuck. It was supported with a rotating pike to ensure its rigidity. The

Table 2. **Certified properties of the additional materials used for spraying 1**

Certified property	Wire type	
	Ni – Al wire	Cr – Mo steel, ≈
Composition	20 % Al 80 % Ni	0,38 % C; 0,03 % S; 0,03 % P; 0,75 % Si; 0,38 % Mn; 13,5 % Cr; 13,5 % Mo
Hardness	38 – 40 HRC	40 – 50 HRC
Melting point	1100 °C	1100 °C
Surface roughness	Mid-high	Mid-high

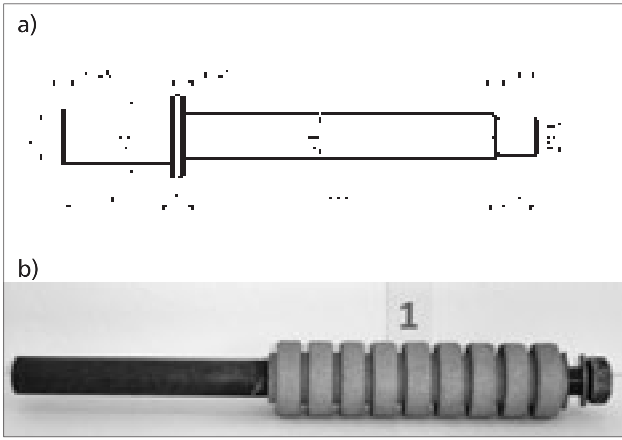


Figure 5. Specimen bearing (a) and a set of sprayed specimens (b)

feed rate of the spray gun mounted onto the lathe was set at 3 mm per specimen revolution. The distance between the specimens and the air outlet of the gun was $L = 150 – 200$ mm (Figure 6). During interlayer spraying, the tip of the wire was fixed to 1,5 mm inside the gun outlet. During final spraying, it protruded 12 to 15 mm. This setting was fixed altering the length of wire protrusion up to constant melting without splatter.

THE RESULTS OF THE MICROSTRUCTURE AND HARDNESS TESTING OF THE SPRAYED COATINGS

The samples were cut from the sprayed specimens in order to examine the surface and in-depth structure and hardness. Figure 7 illustrates the cross-sections of the sprayed specimens. Figure 8 shows the microstructure of the interlayer and the final coating. The thickness of the sprayed coatings was measured, as well as their cross-sectional HV 0,1. These results are given in Table 3 and 4.

The surface hardness of sprayed coatings was determined using the Vickers method and a load of 300 N for five consecutive measurements on each specimen. The values for the specimens 1 - 5 did not differ and ranged from 178 to 206 HV 30.

RESULT ANALYSIS AND CONSLUSION

The results of cross-sectional hardness measurement of coatings and along referential HV 0,1 – lines both indicate a difference in the layer thickness. The maximal layer thickness of ≈ 2 mm was measured on the specimens 2; 3

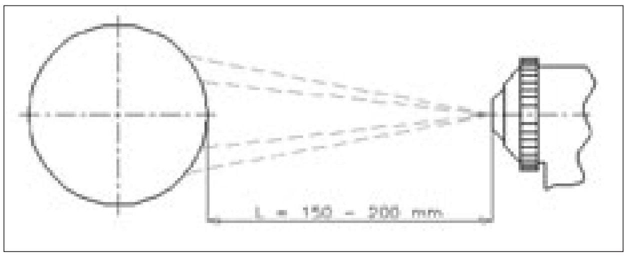
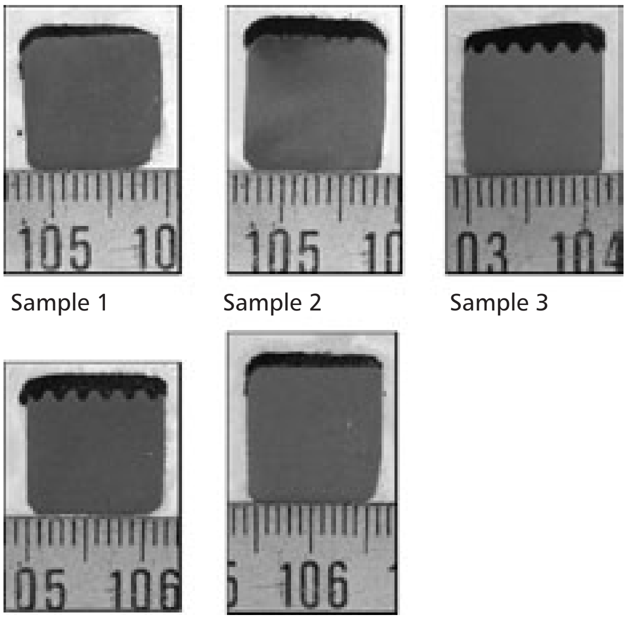


Figure 6. The position of the spray gun during thermal spraying



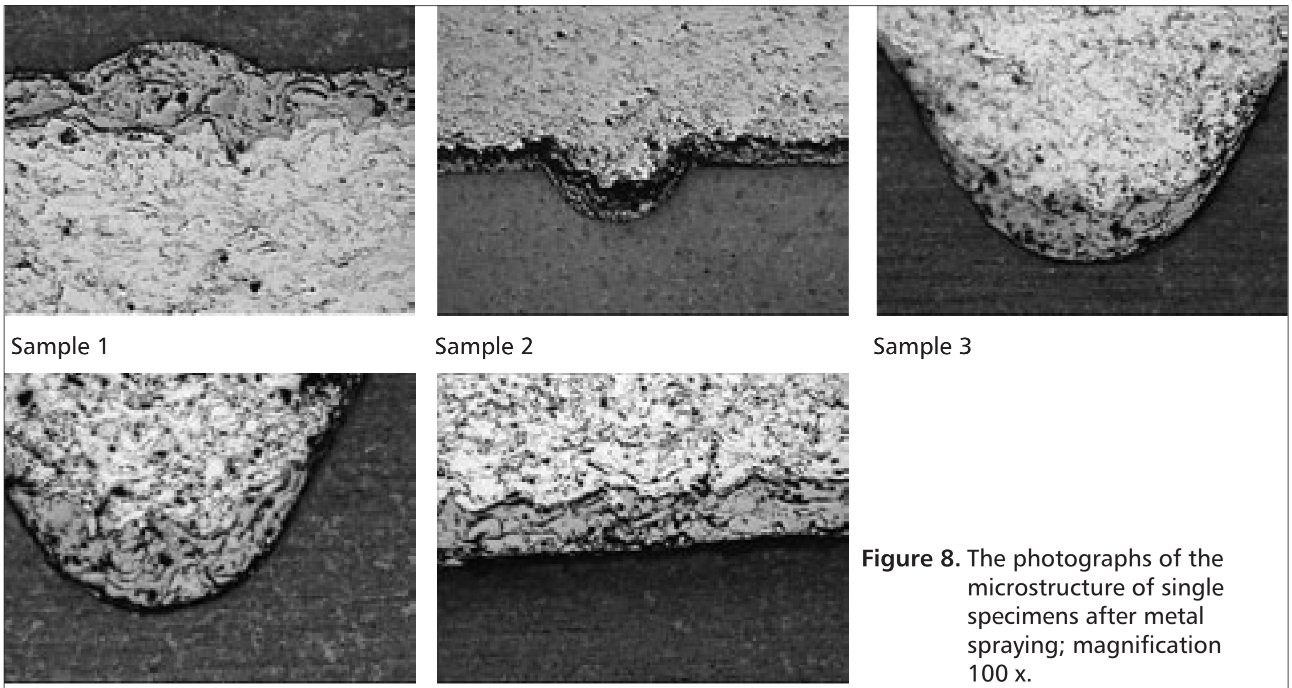
Sample 1 Sample 2 Sample 3

Sample 4 Sample 5

Figure 7. The photographs of the cross-sections of sprayed coatings with a different surface preparation

Table 3. **Hardness values for the sprayed coatings and the base material**

	Distance / mm	Sample 0 / HV 0,1	Sample 1 / HV 0,1	Sample 2 / HV 0,1
Sprayed	2			254
	1,5			170
	1			254
	0,7			165
	0,5			228
	0,4		128	187
	0,3		254	170
	0,2		274	245
	0,1		297	297
	0,05		401	297
	0		206	297
Base material	0,05	221	181	187
	0,1	228	181	206
	0,2		193	206
	0,3		170	206
	0,4		160	206
	0,5		160	
	1		142	
	1,5		160	
	Core	254	116	221



Sample 1 Sample 2 Sample 3

Sample 4 Sample 5

Figure 8. The photographs of the microstructure of single specimens after metal spraying; magnification 100 x.

Table 4. **Hardness values for the sprayed coatings and the base material**

	Distance / mm	Sample 3 / HV 0,1	Sample 4 / HV 0,1	Sample 5 / HV 0,1
Sprayed	2	181	213	
	1,5	206	176	193
	1	181	206	206
	0,7	143	199	206
	0,5	199	199	221
	0,4	180	187	245
	0,3	228	383	254
	0,2	274	401	245
	0,1	245	245	297
	0,05	297	351	351
	0	187	221	245
Base material	0,05	213	228	297
	0,1	203	206	264
	0,2	213	193	254
	0,3	193	193	221
	0,4	193	193	213
	0,5	193		221
	1			221
	1,5			221
	Core	206	213	176

and 4. For the specimen No. 5, the layer thickness was established with ≈ 1,5 mm. The specimen No. 1 had the lowest thickness of ≈ 0,4 mm. The specimens 2; 3 and 4 showed the lowest scattering of measured hardness values across the layer. A comparison of HV 0,1 values illustrates the influence of base material surface preparation prior to thermal spraying. The cross-sectional hardness distribution is further confirmed by means of a metallographic structure analysis. The final layer is found to be of varying thickness and with clearly visible porosity. The specimens with a dented base surface exhibit a distinctive interlayer and a homogeneous, fine-grained microstructure. Further testing with the adequate examination methods should offer an insight into the characteristics and the types of microstructure constituents within respective layers and their effect on the bond quality between the base material, the interlayer and the final coating. Therefore, it can be concluded that both the hardness and the layer thickness depend on the quality of base material surface preparation. The dented surfaces, i.e. maximized bonding surfaces between the roughened base material and the sprayed coating, exhibit the thickest sprayed coating. This experiment has identified a method and a type of surface preparation that secures the acceptable spraying thickness and the desired hardness. Some further experiments should serve to test shear behaviour and offer a detailed comparison of coatings with respect to the base material surface preparation and the related bond quality.

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Note: Responsible translator: Željka Rosandić, Faculty of Mechanical Engineering, University of Osijek, Slavonski Brod, Croatia