

# Modification of Surface Layers by Surfacing Intermetallic Coatings with Variable Properties

**D N Makeev<sup>1</sup>, O V Zakharov<sup>1</sup>, A N Vinogradov<sup>1</sup>, A V Kochetkov<sup>2</sup>**

<sup>1</sup> Yuri Gagarin State Technical University, Saratov, Russia,

<sup>2</sup> Perm National Research Polytechnic University, Perm, Russia

E-mail: zov17@mail.ru

**Abstract.** The paper considers the possibility of forming coating layers for parts within wide limits of microhardness. The technology uses surfacing of intermetallic coatings provided by a unique experimental setup. Theoretical and experimental dependence of the coating layer microhardness on the filler concentration using the changes in the speed of the filler wire feed and current intensity were determined.

## 1. Introduction

One of the fundamental problems in modern engineering is improvement of reliability of machines and mechanisms which is connected with upgrading the durability of their components. For this purpose it is necessary to improve the quality of the mating surfaces, primarily those operating under conditions of rolling or sliding friction. With continuous reduction of raw material resources and the need for increasing energy efficiency of the production process, manufacturing of components with advanced types of covering becomes of major importance [1-3]. The coating allows for changes in the technology, and utilization of work pieces made of inexpensive materials characterized by poorer physical and mechanical properties, and subsequently, allows for modification of the working surfaces using high-strength alloys. The surfacing provides the possibility for coatings with the thickness ranging from 0.1 to 10 mm. The given process facilitates reconditioning expensive parts, such as workpieces for vehicles, which are subjected to the highest wear while in operation.

At this stage, development of new approaches in the design of construction materials and creation of efficient technologies for their fabrication are needed. Modification of the coating layers using the surfacing of intermetallic coatings might be one of the required methods [4-7]. The given technology was first developed at Yuri Gagarin State Technical University of Saratov and went through the experimental pre-check needed to produce new and restore worn-out parts of vehicles.

## 2. Theoretical Estimates

An overview of existing surfacing technologies with further machining showed that the basic studies focus on resolving the following problems: improving the quality of the surfacing metal, enhancing alloying process, increasing the surfacing rate, reducing the costs of surfacing and further machining processes. The quality of the surfacing layer, to a great extent, can be defined by the following characteristics: structure refinement, reduction of the heat-affected zone, reduction of specific heat input, and, consequently, reduction of internal stresses and deformation in the post-surfacing period.

While surfacing the coating is provided by melting the filler and the near-surface layer of a work piece, their fusion and further crystallization over the covered work piece. The welded joint



crystallizes as separate layers with the thickness rate at hundredths of a millimetre. The layered structure of the crystallized metal is due to periodic shutdowns caused by delays of temperature reduction in the welding bath before the crystallization front simulated by the latent heat release. The process of heat elimination of heat into the base metal is followed by crystallization of the melt layer in the coating metal. The intermittent nature of primary crystallization of the melt metal bath impacts the formation of stratified inhomogeneity where the lower part of the layer is characterized for concentrated ratio of alloying elements, while the upper part of the layer if compared to the middle part is characterized for depletion of these elements. When under cooling, the melt discharges crystalline grains with high concentration of refractory components, whereas the concentration of fusible components is rising in the non- solidified part of the melt. Thus, the surfacing metal becomes chemically inhomogeneous.

Two competing processes develop during solidification of the metal: formation of chemical inhomogeneity of the material and diffusion leading to the levelling of the compound in different areas of crystalline grains. However, full homogenization of the metal does not occur, which results in the development of zonal segregation and intradendritic heterogeneity. Segregation of the various chemical elements has its own peculiar features influencing each other. For example, an increase in the concentration of carbon in the surfacing metal strengthens segregation of manganese, molybdenum, silicon and chromium. Thus, alloying the surfacing metal using several elements results in their sophisticated interaction on the pattern of metal inhomogeneity. Chemical inhomogeneity of the surfacing metal is also connected with the surfacing technology itself and characteristics of the materials used in the coating process. The main reason for inhomogeneity at single-layer surfacing provided by separate beads is higher intensity of metal alloying in the overlapping areas. With increasing the duty cycle of the flux cored wire or powder-coated tape, the scattering of the material decreases and conditions for the welding beads formation improve, therefore inhomogeneity of the surfacing metal decreases.

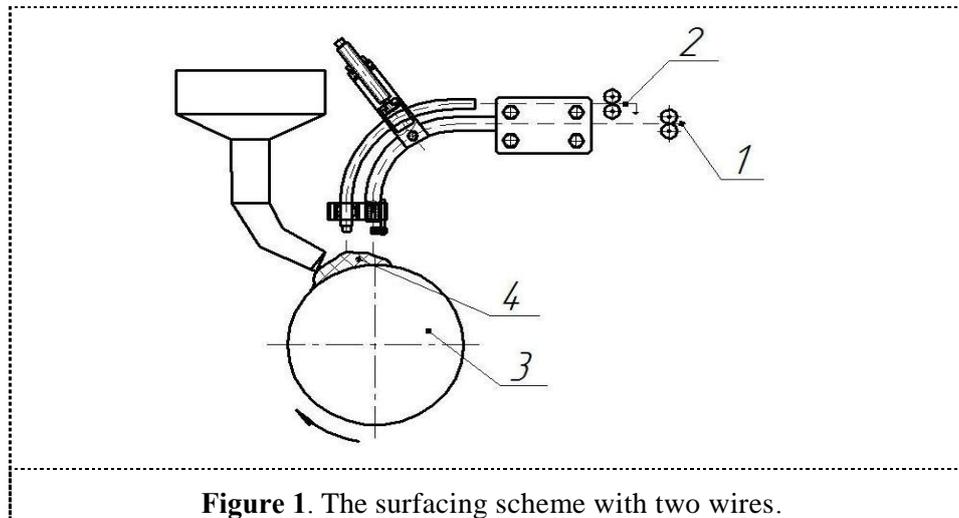
Physical inhomogeneity of the surfacing metal is connected with certain defects in the crystal lattice. The majority of defects occur during the dendritic crystallization typical of the surfacing metal. Dendrite branches are characterized for a variety of spatial orientation, while crystalline grains have block structure strengthened due to additives and dislocation between the branches of dendrites. At melt cooling during the crystallization process, we can observe the volume contraction of the coating material. The shrinkage effect creates significant stresses within the crystallized metal. If the shrinkage effect exceeds the existing resistance of material, then hot cracks occur in the coating. Metal cooling is accompanied with the increase of cracks under the stress caused by uneven heating. The changes in the chemical and physical inhomogeneity of the surfacing metal, cause the changes in its physical-mechanical properties.

In the course of preliminary studies, we found the possibility for directional formation of properties of intermetallic coatings during the surfacing procedure. The possibility can be realized by means of introduction of a separate filler wire into a specified point of the welding bath. As a result, heat removal conditions are created leading to reduction of the heat-affected zone and internal stresses. Thus the elements of the filler wire alloy the metal of the joint.

Using the above data, we suggested a hypothesis which relates the possibility of quality management of the surfacing layer using the changes of machining conditions. To conduct the experiments, a unique setup was developed. Preliminary studies proved the fact of microhardness changes in the coating layer ranging from 28-32 to 45-55 HRC.

### 3. Experimental Procedure

To obtain the intermetallic coating, we used the surfacing method with the flux layer and additional grounded aluminium filler wire (patent RU 2403138). The surfacing was performed with the 30XГCA base wire and  $AlMg_3$  filler wire. For wire feeding (base and filler) we utilized the surfacing head (patent RU 2494843). Figure 1 shows the surfacing scheme with two wires – the base and the filler, where 1 – the base wire, 2 – the filler wire, 3 – the work piece, and 4 – the flux.



**Figure 1.** The surfacing scheme with two wires.

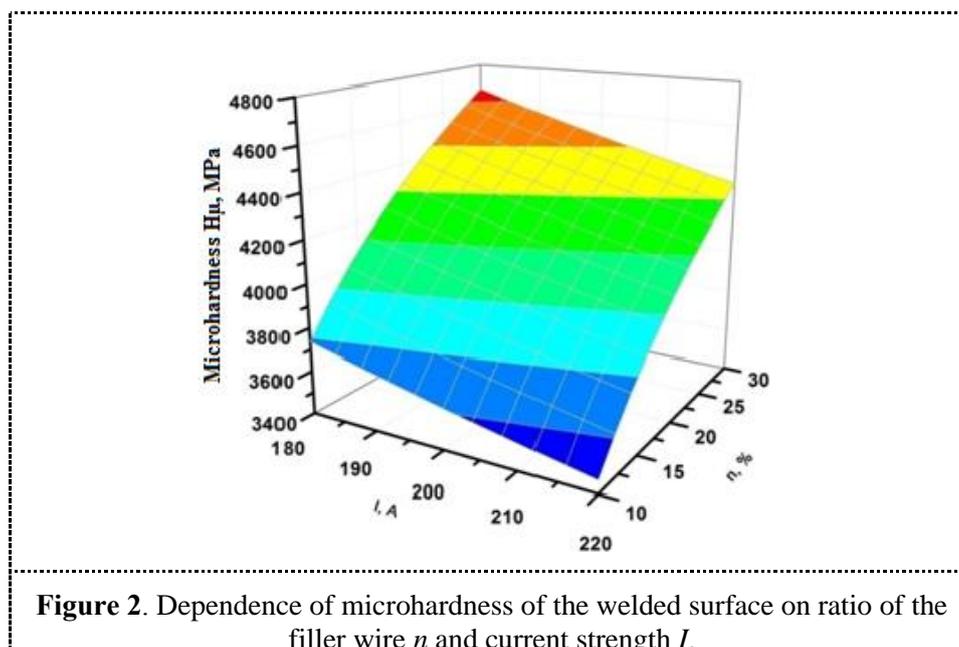
The aim of the experiment study was to define the influence of the alloying constituent ratio (aluminium) on the microhardness of welded coating layers, find out empirical dependence of microhardness on the surfacing mode, and research the distribution of the hardness profile over the depth of the surfacing layer.

To determine the influence mechanism of the analyzed factors on the results of intermetallic coatings, we used the interpolation models developed on the basis of power functions. Microhardness of the coating layer  $H\mu$  was used as the factor of dependency on the percentage of the filler wire  $n$ , % and current strength feeding the base wire  $I$ , A.

After transformations according to the formulas shown above, we obtained the following empirical dependency:

$$H\mu = 17500 \cdot n^{0.2} \cdot I^{-0.38}. \quad (1)$$

According to the formula (1), the microhardness increases depending on the increase of ratio of the filler wire  $n$ , whereas the increase of the current strength  $I$  leads to an insignificant decrease in the microhardness. The chart (Figure 2) shows the influence of each factor on the microhardness of the welded surface.



**Figure 2.** Dependence of microhardness of the welded surface on ratio of the filler wire  $n$  and current strength  $I$ .

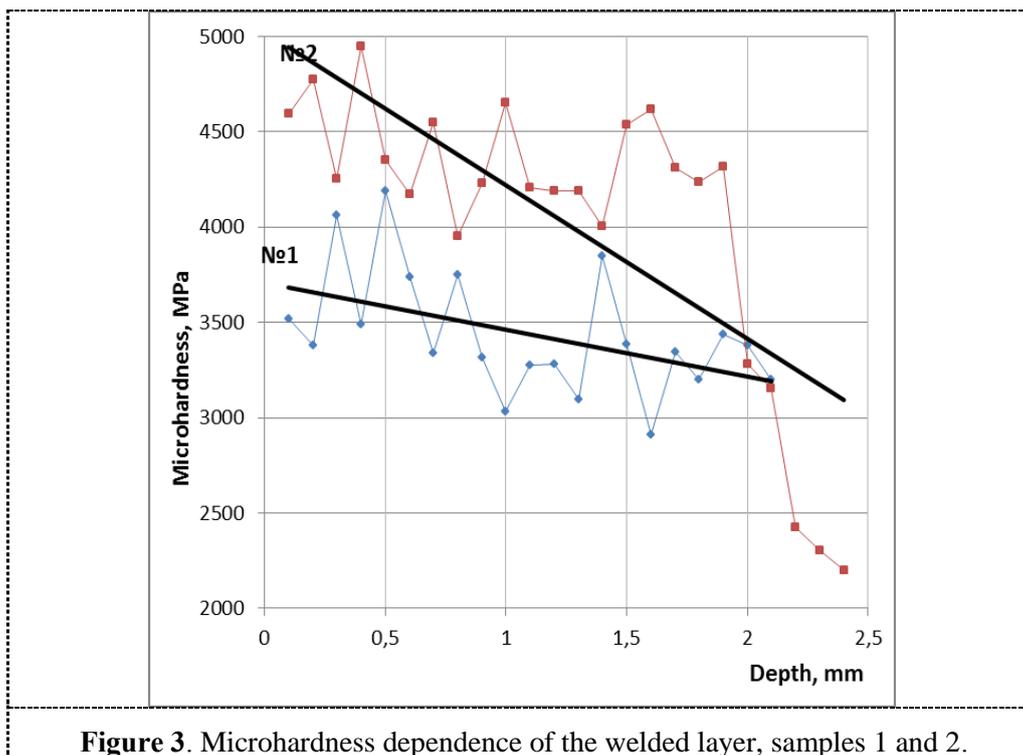
When increasing the filler wire feed speed, the percentage of filler constituents in the welding bath increases. Thus, the number of intermetallic compounds increases, and consequently, results in the increase of microhardness of the coating layers.

When increasing the current strength, the temperature of the welding bath increases, which facilitates evaporation of the constituent alloying materials in the base wire and constituent materials in the filler wire, since the melting temperature is significantly lower than the melting temperature of steel. Thus, the increase of the current strength causes decrease of microhardness of intermetallic coatings.

#### 4. Results and Analysis

Let us consider the microhardness behaviour of the welded intermetallic samples along the depth of the surfacing layer.

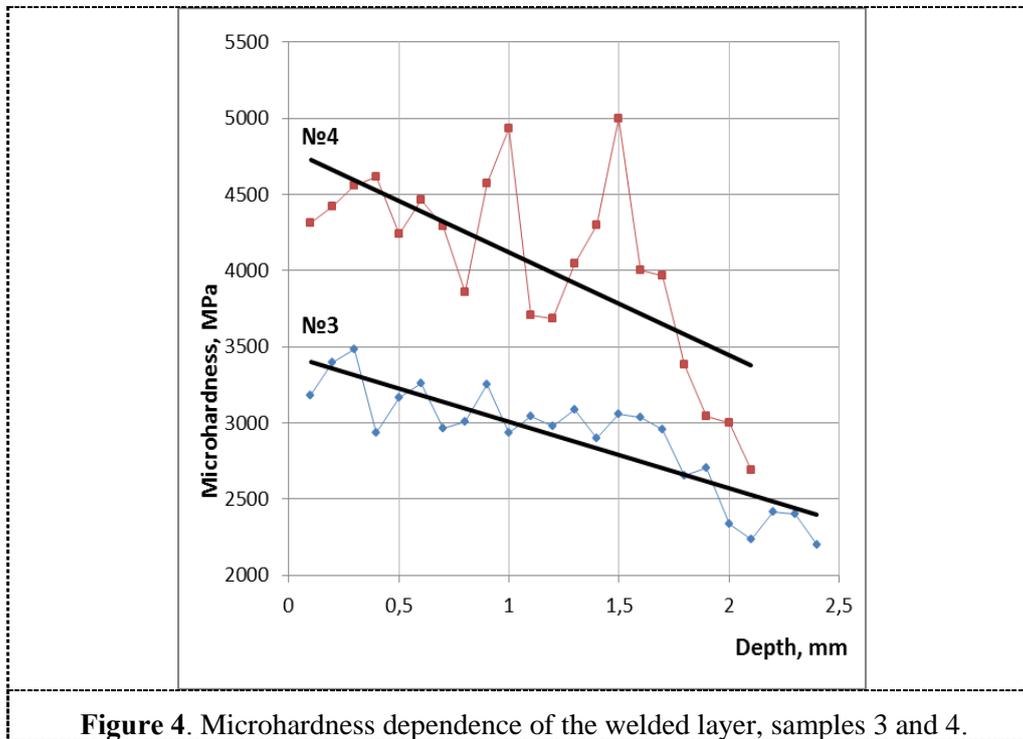
The chart (Figure 3) shows that microhardness of sample 2 is higher than that of sample 1, which is interconnected with the percentage of the filler material in the samples. The more the percentage of the filler material, the higher the microhardness of the surface. This is proved by the results of the secondary ion-ion emission, which demonstrates that sample 2 has 2 or 2, 5 times more aluminium compared to sample 1.



Concentration ratio of other alloying materials in the samples is the same, since these materials make the constituent part of the base wire. The feeding speed and current strength of the wire remains unchanged during over the whole stage of the experiment.

The chart (Figure 3) shows that microhardness of sample 4 is higher than that of sample 3, since the percentage of the filler material in sample 4 is higher than that in sample 3. The maximum microhardness ratio of sample 2 is insignificantly higher than in sample 4.

This is connected with the current strength in the base wire, since the increase of the current strength results in the temperature increase in the welding bath, and consequently, leads to evaporation of alloying materials. Therefore, concentration of the aluminium in sample 4 is 1.3% less than in sample 2.



**Figure 4.** Microhardness dependence of the welded layer, samples 3 and 4.

## 5. Conclusion

The research proves the hypothesis referring the possibility of directional changes in the properties of the surfacing layers by means of surfacing intermetallic coatings. For the samples and real vehicle parts, we obtained the changes of surface microhardness ranging from 28-32 to 45-55 HRC depending on the surfacing conditions.

Using a complete factorial experiment, we obtained empirical dependency of microhardness in the welded coating layers on the filler concentration and current strength. The given data prove that the developed method of surfacing intermetallic coatings used for coating new parts and refacing worn-out parts can be recommended for application.

## References

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