

# Comparative evaluation of wear resistance surfacing with feeding of nanooxides and nanocarbides to weld pool

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**Abstract.** The paper presents the results of testing wear resistance of deposited metal, modified by silicon nanooxides and titanium nanocarbides through the weld pool with scheme of its feeding by paraffin rod. It is shown that feeding both nanooxide and nanocarbide to weld pool increase wear resistance of deposited metal up to 4 times. Both nanooxide and nanocarbide feeding to weld pool leads to some changes in the structure increasing martensitic component and, as a result, hardness of deposited metal. In all the cases of testing the microhardness of deposited metal, modified by nanocarbides is higher than that with nanooxides. Volume fraction of nonmetallic inclusions is a bit higher in deposited metal, modified by nanooxides and nanocarbides. It is proposed to use paraffin rod as technological scheme of feeding nanocomponents into the weld pool in the surfacing processes. To increase wear resistance of deposited metal, it is recommended in the arc welding surfacing processes to use silicon nanooxide, considering its low price and accessibility on the market.

**Keywords:** Surfacing, Wear Resistance, Nonmetallic Inclusions, Nanooxides, Nanocarbides, Structure.

## 1.0 Introduction

The operating conditions of machine parts and constructions are often accompanied by wear of their surfaces as a result of various types of friction, corrosion attacks, impact loads and heat changes. One of the most common technological processes of the reconditioning of the worn parts is arc welding, which achieves the desired working layer on the surface of the product. Restoration of operability of worn parts can be achieved by two ways: either changing of worn parts by new ones or applying on the worn surface a coating of the specified thickness and with the required operating characteristics. The second way is more profitable because the cost of weld surfacing usually is not more than 30 % the whole price of the new detail.

Surfacing process effectively prolongs the service term of technological unit. To solve this problem, an important role is given to methods that allow controlling the structure of the deposited metal. One of such methods is connected with nonmetallic inclusions.

Over the recent years a significant role of nonmetallic inclusions, as a factor controlling cast metal structure and properties, has been noted in publications [1–6]. Precipitation of such inclusions in the form of oxides, carbides and nitrides in weld metal was considered to be the result of chemical bonding of the respective elements during the solidification, whereas the inclusions proper, both of up to 1  $\mu\text{m}$  size range, and close to nanosized range, were given the role of inoculators.

A positive influence of inclusions of certain composition, dimensions and distribution density on weld structure and properties is noted in all the cases.

The main part of studies was performed for welding of low alloyed high-strength steels. The results of investigations in this area are generalized in [7].

Information on their influence on deposited metal wear resistance is limited, although the available experience of applying both nanooxides in plasma surfacing and nanocarbides in electrode coatings points to good prospects for their application in surfacing processes. An insignificant (up to 0.2 wt.%) amount of nano-sized particles of tungsten carbides was used in electric arc and electroslag surfacing [8, 9].

Fine crystalline structure of the deposited metal was achieved by applying particles both directly to the weld pool and with welding materials. Nanodispersed carbides, bypassing the high-temperature reaction zone without being completely dissolved, pass into the weld metal, causing its modification.

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Feeding into the weld pool aluminum, titanium and silicon nanooxides is studied in [10]. Three different schemes feeding of nanooxides into the weld pool were used. It is shown that regardless of schemes feeding nanooxides to weld pool leads to a noticeable increase of deposited metal wear resistance.

A special interest is related to nanotitanium carbide. Characteristics of the bonding forces in the titanium carbide are much stronger than in all materials except diamond. The most hard carbides in wear-resistant alloys are formed with the ratio of the atomic amount of titanium to carbon:  $C / Ti = 0.24 - 0.45 \%$ . It is considered that at other equal conditions the higher the carbide hardness, the higher the deposited metal wear resistance [11]. In literature the information about the influence of titanium nanocarbides on the structure and wear resistance of deposited metal is absent.

The object of the work was experimental study of deposited metal wear resistance at feeding titanium nanocarbides and silicon nanooxides into the weld pool and comparative evaluation their effectiveness.

## 2. Experimental Methods

Nano-components were provided to the weld pool by paraffin rod formed by the homogeneous mixture of paraffin fractions and silicon oxides or titanium carbides nanopowders (40 nm) of pre-defined volumetric ratio. The paraffin rod having a specified length and diameter was applied to fix nanopowders on the surface in a thin layer across the bead width for the entire length of the deposit prior to surfacing.

In the process of surfacing when heated above  $40^{\circ}\text{C}$ , paraffin evaporates and only nanopowder remains on the surface on which the surfacing is performed.

The tests involved the use of the 09G2S low-alloy high strength steel and the Veltek-H300PM-S filler metal wire. Chemical composition of base and deposited metal is shown in table 1.

Table 1

Chemical composition of base and deposited metal, wt, %

Elements	C	Mn	Si	Cr	S	P
Metal deposited by Veltek-H300PM-S wire	0,22	1,1	0,8	1,1	0,018	0,017
St09G2C base metal	0,09	2,0	0,8			

Modes of surfacing: current  $I = 300 \text{ A}$ , arc voltage  $U = 30 \text{ V}$ , speed of surfacing  $V = 16 \text{ m / h}$ .

For the conditions of metal-to-metal friction, wear resistance tests were carried out on a SMTS-2 type friction machine according to the shaft-to-block scheme on samples 20 mm long and 10 mm wide. A 50 mm disk made of steel U8 with a hardness of HB 400–450 was used as a counterbody.

Test conditions: pressure on the sample –  $P = 0.1 \text{ MPa}$ ; friction velocity –  $V = 0.8 \text{ m / s}$ ; test temperature –  $T = 20^{\circ}\text{C}$ ; test duration – 2 hours with measurements every 15 min.

Samples were weighed before and after testing in accurate laboratory scales with 0,001 g error. Mass wear was determined as the difference between the sample mass values before and after the tests.

## 3. Obtained Results

Testing of deposited metal welded with Veltek-H300PM-S wire showed (Fig. 1) that at feeding of nanopowders into the weld pool, metal wear resistance is increased both in the presence of nanooxides of silicon and nanocarbides of titanium.

Maximum effect is observed at feeding of 7 % and 10 %  $\text{SiO}_2$ , 5 % and 10 %  $\text{TiC}$  into the weld pool with mass losses decreasing from  $\Delta m = 0,01 \text{ g}$  ( initial bead, curve 1) to  $\Delta m = 0,037-0,04 \text{ g}$  ( curves 2,3 and 6,7), i.e. by 3,8–4 times.

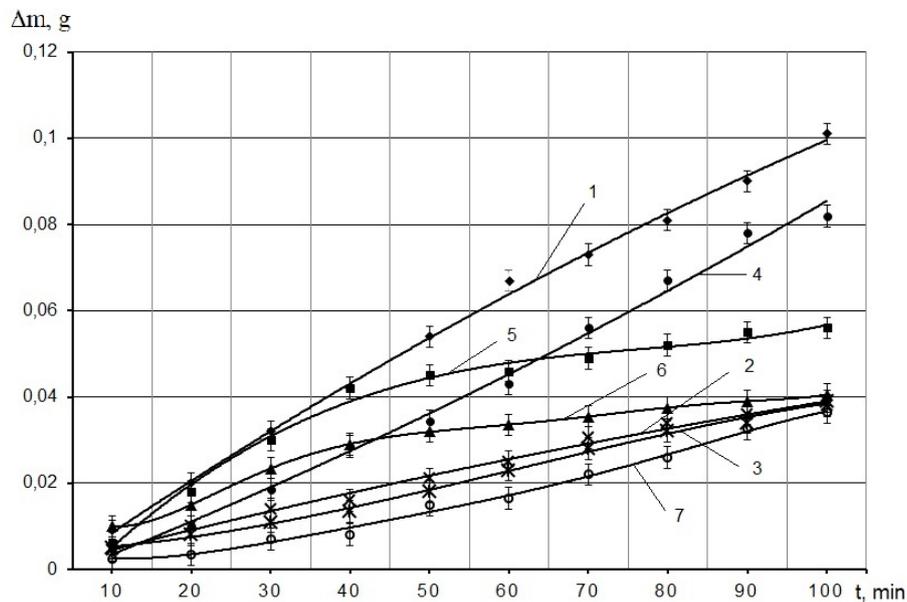
Smaller amounts of titanium nanocarbides (0,5 %  $\text{TiC}$ , 1%  $\text{TiC}$  ) promote improvement of deposited metal wear resistance ( compare curves 4,6 and curve 1 for initial bead), while mass losses in this case are reduced only 1,2 and 1,8 times respectively.

Microhardness measurements showed (Table 2 ) that at average value for bead initial metal  $HV 2,8 \text{ GPa}$  in the other cases increased, reaching maximum  $HV 4,05 \text{ GPa}$  for 5 %  $\text{TiC}$ . In all cases microhardness of the beads with titanium nanocarbides is higher than the microhardness the beads with silicon nanooxide. A correlation between deposited metal hardness and wear resistance is observed for both nano additives.

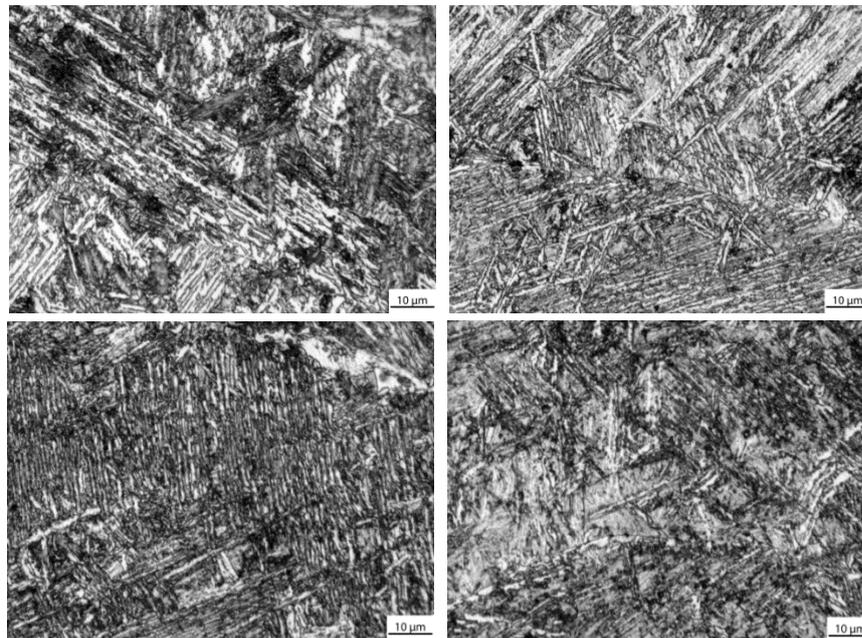
Analysis showed that initial bead metal has bainite structure with a very small amount of troostite component (Fig. 2, a). Deposited metal with silicon dioxide is characterized by bainite-martensitic structure that, apparently, is exactly what determines wear resistance increase (Fig. 2, b). The same type of structure is observed in deposited metal with titanium carbides but only with a bit higher value of martensitic component (Fig. 2, c, d) that explains the higher microhardness.

Results of analyses of distribution of nonmetallic inclusion quantity revealed that in initial condition without additives their volume fraction is equal to 0,29 %. In the metal of the bead with 10 %  $\text{SiO}_2$  nanooxide the volume fraction

of nonmetallic inclusions is somewhat greater and is equal to 0,34 % and to 0,3 %, 0,33% with 5 % and 10 % TiC nanocarbide respectively.



**Fig. 1.** Wear resistance of metal deposited with Veltek-H300PM-S wire: 1 – initial bead; 2 – 7% SiO<sub>2</sub>; 3 – 10% SiO<sub>2</sub>; 4 – 0,5% TiC; 5 – 1% TiC; 6 – 5% TiC; 7 – 10% TiC;

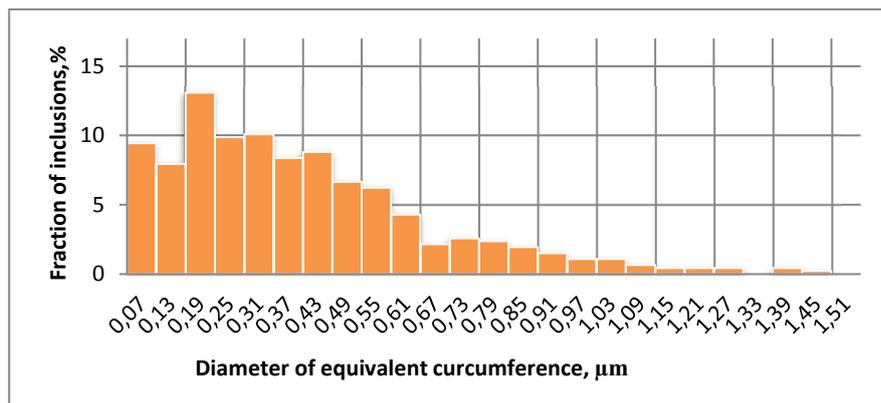
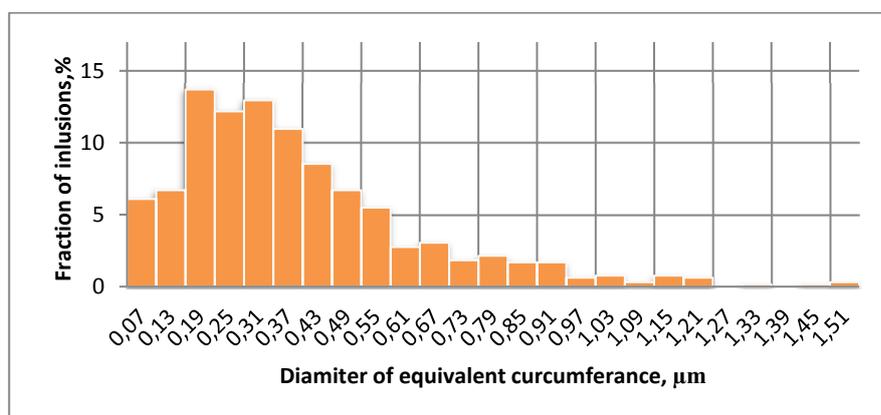
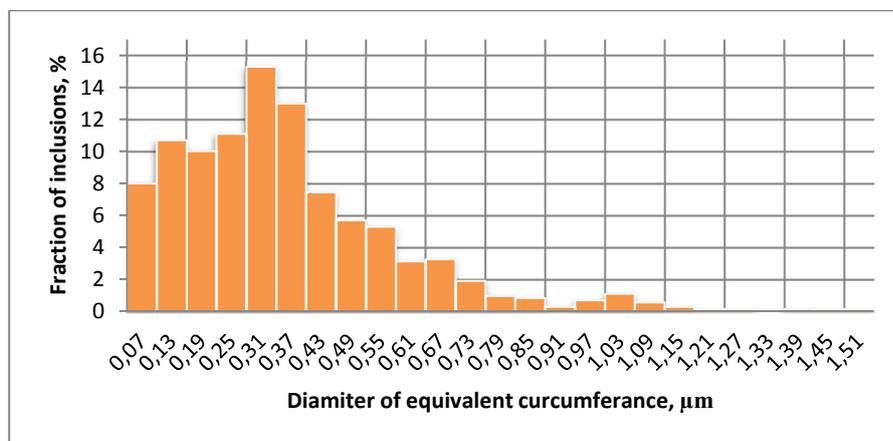


**Fig. 2.** Microstructure of deposited metal without (a) and with (b) 10% SiO<sub>2</sub>, (c) 5% TiC, (d) 10% TiC

The main regularities are studied by the results of processing the dimensions of inclusions of just spherical shape by the parameter of equivalent circumference diameter. For instance, Fig. 3 gives the histograms by volume fraction and distribution of such inclusions in the deposited metal for initial condition and in the presence of silicon nanooxide and titanium nanocarbide.

In the metal for initial condition volume fraction of spherical inclusions from 6 up to 13 % is in the dimensional range to 0,07–0,55 μm and from 1 up to 4 % inclusions are in the dimensional range 0,61–1,03 μm (Fig. 3, a).

In the metal of the bead with 10 % SiO<sub>2</sub> nanooxide the volume fraction of nonmetallic inclusions from 6 up to 14 % correspond to dimensional range of 0,07–0,49 μm and from 1,5 % up to 5,5 % to dimensional range of 0,55–0,91 μm (Fig. 3, b).

*a**b**c*

**Fig. 3.** Histogram of inclusion distribution in deposited metal by the parameter of equivalent circumference:  
*a* – in the initial condition; *b* – with 10 % SiO<sub>2</sub>; *c* – 10 % TiC

At addition 10 % TiC nanocarbide, the fraction of spherical inclusions in the range 0,07–0,43 rises from 8 up to 15 % and from 2 up to 6 % of spherical inclusions are in dimensional range 0,49–0,73  $\mu\text{m}$  (Fig.3, *c*).

Comparative analysis of the data points to an increase of volume fraction of inclusions in the dimensional range of 0,19–0,43  $\mu\text{m}$  up to 14–15% at feeding both SiO<sub>2</sub> nanooxide and TiC nanocarbide. Presense of inclusions of more than 0,67  $\mu\text{m}$  is observed in all cases. The fact of nonmetallic inclusions coarsening in this case may be associated with their coagulation and coalescence with nonmetallic inclusions of material during weld pool solidification.

#### 4. Discussion

The experimental results showed that the effect of increasing wear resistance is also observed when applying the scheme of feeding nanopowders into the weld pool by paraffin rod. The effect of wear resistance increasing is approximately equal to those obtained in [10]. When nanocomponents were added in the form of master alloy compacting and sintering of homogeneous mixture of iron powders and nanopowders with specified volume ratio, or in other schemes the mixtures after their processing in a planetary- type mill were first fixed by priming and then were applied in a thin layer across the bead, or the same scheme for feeding just nanooxide powders into the weld pool with recalculation of their weight fraction to weld pool volume.

Thus, in spite of different schemes and different materials used in experiments positive effect is noted in all the cases. In relation to surfacing conditions, the scheme with paraffin rod is more technologically advanced in comparison with the three previously studied.

The almost identical effect of increasing wear resistance when feeding into the weld pool titanium nanocarbitides compared to silicon nanooxides is somewhat unexpected. As was mentioned, the harder the carbide, the higher the wear resistance. Carbides are the main hardening phase in hard alloys and among other carbide formers, titanium carbide has the highest strength, its microhardness is 32,000 MPa. [12].

The data table 2 also indicate a slight increase in the microhardness of the deposited metal modified with titanium nanocarbitides. From this, we can conclude that, perhaps, in the deposited metal, the main carbide-forming element is replaced by other elements, which can affect the properties of the formed carbides. Perhaps, there are other factors that require additional research. The fact of the modification of the deposited metal with nanooxides and nanocarbitides is confirmed by the data on the number of inclusions present in the deposited metal

Aerosil (silicon dioxide) is manufactured on the commercial scale and, considering significantly lower price of aerosol relative to titanium nanocarbitides, is more preferable for that surfacing technology,

Table 2.

Microhardness of deposited metal

No. of the sample	The composition of the sample	Microhardness values measured HV, GPa					Average value microhardness, GPa
1	Initial (without nanoadditives)	2,54	2,54	3,22	2,97	2,74	2,8
2	5% SiO <sub>2</sub>	2,97	2,74	3,22	4,2	3,22	3,27
3	10% SiO <sub>2</sub>	2,74	3,22	3,51	3,51	3,51	3,3
4	0,5% TiC	3,51	3,51	4,64	2,97	3,83	3,69
5	1% TiC	3,51	2,97	2,97	3,83	3,51	3,34
6	5% TiC	3,83	3,83	4,2	4,2	4,2	4,05
7	10% TiC	3,83	3,51	3,83	3,83	3,51	3,7

#### 5. Conclusion

1. It is established that titanium nanocarbitides provide the same effect on wear resistance of deposited metal as silicon nanooxides do. Both of nanopowders may increase wear resistance of deposited metal up to 4 times.

2. For implementing the technology it is preferable to use silicon dioxide considering the fact that this nanopowder is manufactured on the commercial scale and is much cheaper than titanium nanocarbitide

3. For weld surfacing technology using paraffin rod for feeding nanopowders into the weld pool is recommended due to simplicity and accessibility the scheme.

#### Disclosure

##### Authors' contributions

All authors participated in the design of this work and performed equally. All authors read and approved the final manuscript.

##### Compliance with ethical guidelines

Competing interests. The authors declare that they have no competing interests.

#### Nomenclature

$I$  – arc current;

$U$  – arc voltage;

$V$  – speed of surfacing;

$HB$  – hardness tested by Brunel device;

$P$  – pressure on the sample;

$V$  – friction velocity;

$T$  – test temperature;

$\Delta m$  – mass losses;

$t$  – test duration;

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## Сравнительная оценка износостойкости при наплавке с подачей в сварочную ванну наноксидов и нанокарбидов

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**Аннотация.** В статье представлены результаты испытаний на износостойкость наплавленного металла, модифицированного наноксидом кремния и нанокарбидами титана через сварочную ванну со схемой их подачи парафиновым стержнем. Показано, что подача как наноксидов, так и нанокарбидов в сварочную ванну повышает износостойкость наплавленного металла до 4 раз. Подача наноксидов и нанокарбидов в сварочную ванну приводит к некоторым изменениям в структуре, увеличивая мартенситную составляющую и, как следствие, твердость наплавленного металла. Во всех случаях испытаний микротвердость наплавленного металла, модифицированного наноксидом кремния, выше, чем у наноксидов. Объемная доля неметаллических включений несколько выше в наплавленном металле, модифицированном наноксидом кремния и нанокарбидами титана. Предлагается использовать парафиновые стержни в качестве элемента технологической схемы подачи наноксидов и нанокарбидов в сварочную ванну в процессах наплавки. Для повышения износостойкости наплавленного металла в процессах дуговой наплавки рекомендуется использовать наноксид кремния, учитывая его низкую цену и доступность на рынке.

**Ключевые слова:** наплавка, износостойкость, неметаллические включения, наноксиды, нанокарбиды, структура.

## Порівняльна оцінка зносостійкості при наплавленні з введенням до зварювальної ванни наноксидів і нанокарбідів

В. Кузнецов, Д. Степанов

**Анотація.** У статті представлені результати випробувань зносостійкості наплавленого металу, модифікованого наноксидом кремнію та нанокарбідом титану через зварювальну ванну із схемою їх введення парафіновим стрижнем. Показано, що подача наноксиду та нанокарбиду до зварювальної ванни збільшує зносостійкість наплавленого металу до 4 разів. Введення у зварювальну ванну як наноксиду, так і нанокарбиду призводить до деяких змін у структурі, збільшуючи мартенситну складову і, як наслідок, твердість наплавленого металу. У всіх випадках випробування микротвердість наплавленого металу, модифікованого наноксидом кремнію, вище, ніж у наноксидів. Об'ємна частка неметалевих включень трохи більша в наплавленому металі, модифікованому наноксидом кремнію та нанокарбідом титану. Парафіновий стрижень пропонується використовувати як елемент технологічної схеми подачі наноксидів і нанокарбідів до зварювальної ванни у процесі наплавлення. Для підвищення зносостійкості наплавленого металу рекомендується використовувати наноксид кремнію, враховуючи його низьку ціну та доступність на ринку.

**Ключові слова:** Наплавлення, Зносостійкість, Неметалеві Включення, Наноксиди, Нанокарбідів, Структура.

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