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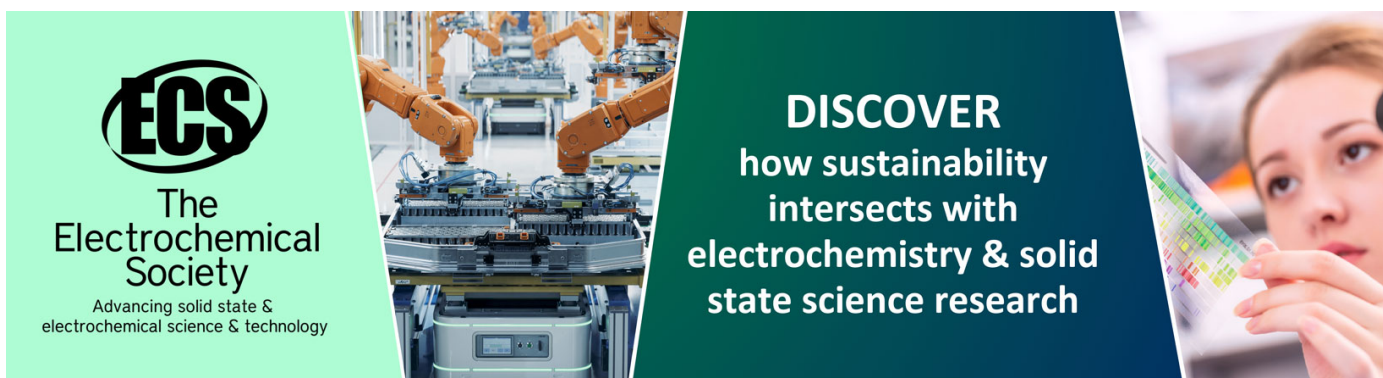
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To cite this article: Layth Zbbal Abd UL Kareem *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1094** 012137

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Influence of Adding Nano Coating Layers on the Hardness and Impact strength Properties for Low Carbon Steel

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Abstract. Nanotechnology is one of the great techniques that helping to considerably improve many technologies and industry sectors such as information technology, homeland security, medicine, transportation, energy, food safety, and environmental science. Low carbon steel is widely used in many applications because it is cheap and it has high workability. However, low surface hardness and impact toughness are its main disadvantages. In this work, the nanocoating of tungsten carbide (WC) has been added to the low carbon steel surface with a thickness of 30, 40, and 50µm by using the thermal spray process with the HVOF technique. The present work aims to investigate the coating layer influence on the hardness and impact toughness. The results showed a significant improvement in the hardness, reaching 94.7%, while the impact toughness improved by 36% for a sample coated with a 50µm comparing with uncoated samples. The improvement in the hardness and impact toughness is due to the good adhesion of nano coat with the steel surface and the high hardness of tungsten Carbide as well as the good toughness of tungsten. The thickness of the coating layer is detected by using the scanning electron microscope images for each spray time. The results show that the coating with a layer of a thickness of more than 50µm will cause flaking and removing the coating layers.

Keywords. Low carbon steel, Tungsten carbide nanoparticles (WC), Hardness, Impact toughness, SEM.

1. Introduction

Low carbon steel (Mild Steel) is one of the most widely used forms of carbon steel as its low price and good workability. This type of steel usually has a carbon content of less than 0.25%wt. They cannot be hardened by heat treatment (to form martensite), so the hardening is usually achieved by cold work. Low carbon steel is often used in automobile body components, structural shapes (I-beams, channels, and angle iron), pipes, construction, and bridge components [1]. In recent years, many studies on enhancing the mechanical properties of this type of steel. When the modified steel pipelines become stronger and tougher, the transportation capability will increase to meet severe conditions [2]. The effect of carbon contents in steel on microstructure investigated and evolution and mechanical properties like (hardness, impact toughness, and abrasive wear). The result showed increasing in hardness and decreasing the impact of toughness due to the transforming of microstructure from lath



martensite to acicular martensite that refining with a high content of carbon [3]. The effects of coating low carbon steel surface (S50C) by ZnO-SiO₂ are studied, and how to protect it from corrosion and increase the surface hardness [4]. The nano coat of Silicon Nitride(Si₃Ni₄) is used to coat the surface of low carbon steel (AISI 1020). It was found a great enhancement in wear resistance and hardness for the coated sample [5]. The mechanical properties of nanomaterial and who can improve the properties by coating the surfaces by nano coat are reviewed, and the silicone carbides with boron carbides led to an increase in surface hardening by more than 6 times [6]. The mild steel used as a substrate coating with Ni-Sic Nanocoatings and Pure Ni by using magnetically assisted pulse electrodeposition (MAPED) from a Watts-type nickel bath containing Sic nanoparticles. The result showed that the mechanical property of specimens by Ni-Sic Nano coating is improved [7]. The tungsten carbide nanoparticle (WC) effects on the mechanical molecules of standard steel (AISI 1020) are studied. The heat treatment process was achieved by cooling and heating the nanoparticle layer (WC). Partial hardness tests for hardness dress were done according to ASTM (G99-05). The results showed that the partial hardness of AISI 1020 was increased by 5.4% [8]. The modified manganese phosphate conversion coating used to protect low carbon steel from corrosion and improving the wear resistance and the surface hardness of it, especially when adding Zinc to the coating layer [9]. The increase in microhardness and fracture toughness using a mild steel metal and adding a layer of (Al₂O₃-13% TiO₂) nanoparticles studied. The method used is plasma spray. The results showed an increase in microhardness of about 15-30% [10]. Stainless steel (SS304) was used as a substrate coating with Alumina (Al₂O₃) (80nm) Nano coating (NC) and with a conventional coating (CC) with 40μm by applying the atmospheric plasma spray technique (APS). The results showed that the mechanical properties of NC samples are better than that of CC, where the hardness is around 270 HVN [11]. The investigation of the properties of Nano-coated tungsten carbide cobalt (WC-CO) insulators is done. The coating process was on two types of UNS G41350 steel plate: flat substrates (100 x 20 x 5mm) and cylindrical substrates (Ø = 25mm, height 25mm). Also, a traditional coating is used to compare them, which is a nanostructured cermet. The results showed a higher hardness compared to the usual coating [12]. The effect of coating the surface of steel (S420) with coating layers of (WC and CeO₂) by using laser cladding technique on the impact toughness are studied. The results showed improvement in impact toughness and hardness of steel when the ratio of CeO₂ less than 1%, but when the ration been more than 1%, the hardness decreased [13]. The Nano coating layer of Tungsten Carbide is used to coat the surface of high chromium cast iron using a thermal spray process and studied the improvement in the wear resistance and microhardness. The result showed that the microhardness increased by a ratio of 34%. [14]. This work aims to study the effect of coating the low carbon steel surface with nanoparticles of tungsten carbides (WC) and how much the improvement will tack place in the surface hardness and impact toughness.

2. Experimental work

2.1. Samples preparation

The chemical composition analysis (Table 1) of the low carbon steel samples that used to prepare the experimental work samples for hardness and impact toughness tests are done according to standard ASTM E415-17 by Spark Atomic Emission Spectrometry device.

Table 1. Chemical composition of low carbon steel.

Composition	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
Experimental %	0.214	0.257	0.808	0.0101	0.0007	0.083	0.0034	0.0968	0.0418	0.176	Bal.
Standard%	0.35 Max.	0.1- .35	0.6-1.05	0.035 Max.	0.04 Max.	0.3 Max	0.12 Max.	0.4 Max	0.126 Max.	0.2 Max.	Bal.

2.2 Material used for the coating process

The nanoparticles of tungsten carbide (WC) had a nano-size of 55nm used as a coating material to coat the low carbon steel samples. The nanoparticles have an actual density of 15500 kg/m³, a melting point of 2870 °C, and a boiling point of 6000 °C.[15].

2.3 Thermal spray technology

The high-velocity oxy-fuel technique (HVOF) is used in the thermal spray process, where the oxygen and acetylene are mixed in the nozzle tube and spray jet to produce a flame at a temperature greater than 3000 °C, Figure 1. The thermal spraying process is used to coat the surface of low carbon steel samples. The gas flow ratio was 3:1 for oxygen and acetylene at an applied pressure of 10 bar for oxygen, and 5 bar for acetylene. The thickness of the coating layer was measured using SEM imaging. Figure 2 shows the schematic of the coating process [14].



Figure 1. HVOF device.

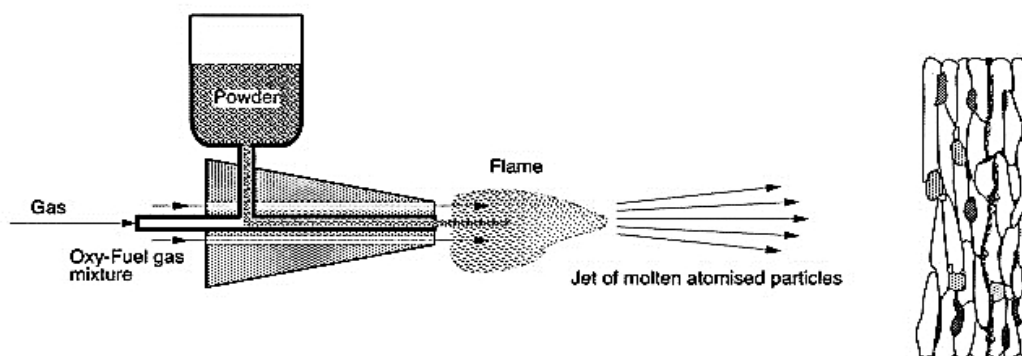


Figure 2. Schematic diagram of the coating process.

2.4 Samples preparation for microhardness testing

The samples for the microhardness test were prepared in the shape of a disc according to standard specification ASTM E92-17 [16], with dimensions of 40 mm diameter and 10 mm thickness made of low carbon steel, as shown in Figure 3.

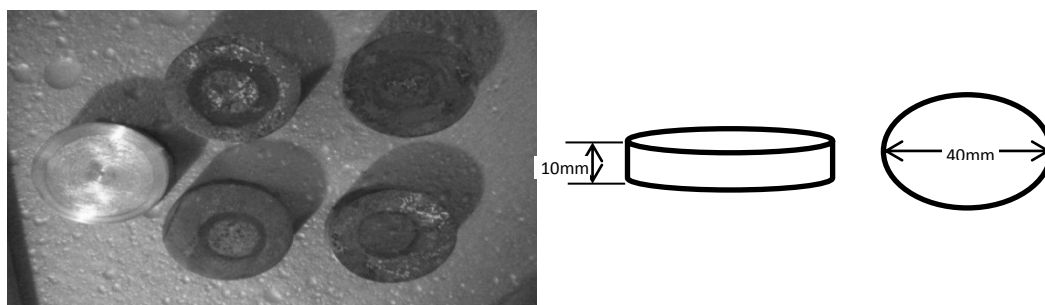


Figure 3. Samples of a microhardness test.

The microhardness test was performed to measure the resistance of the samples to the penetration throughout their surfaces. This test was done according to standard ASTM E92-17, for uncoated and coated samples with a layer coating thickness of 30, 40, and 50 μm by using HVS-1000 Digital Display Microhardness Tester. The conical diamond of hardness tester applied to each sample at three points from the end to its center, respectively, and then calculates the average value, Figure 4. The applied load was 9.8 N for 15 sec from indentation.



Figure 4. **Micro** hardness tester.

2.5 Preparing the impact testing samples

The samples of the impact test are prepared from low carbon steel according to the standard specification of ASTM E2248-18[17], with dimensions of 10 * 10 * 55 mm, as shown in Figure 5.

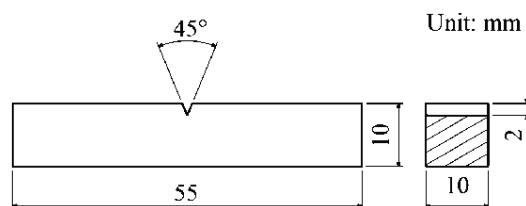


Figure 5. Impact test samples before and after testing.

The impact test demonstrates the ability of the samples to absorb the energy and withstand under the effect of the impact load. The test was performed according to the Charpy impact test. The energy of 600 J was applied to the tested samples (three samples for each test) as a kinetic energy load, as shown in Figure 6.

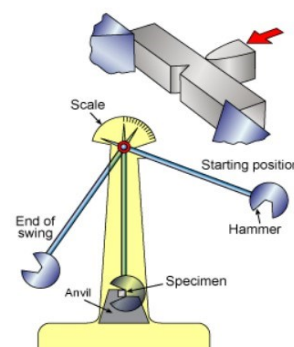


Figure 6. Impact testing machine.

3. Results and discussions

3.1 Results of the microhardness test

Table 2 and Figures 7 and 8 show the results of the hardness tests for samples without and with a coating thickness of 30, 40, and 50 μm . The best improvement ratio in the microhardness test was 94.6% for the sample with a coating thickness of 50 μm , where it was 503.48HV, compared to the sample without coating, where the microhardness reading was 258.7HV. This improvement is due to the high hardness of tungsten carbide (WC), which improves the surface hardening of the sample and reduces the ability of the surface deformations, including the plastic deformation due to its high hardness and toughness properties. Figure 9 shows a nano coat layer of WC with a hardness of more than 1100HV compared to metals whose hardness of 258.7HV [18]. In addition to HVOF, the thermal coating gives them interference in the crystal structure and reduces pores and the ability for the surface penetration.

Table 2. The microhardness results for uncoated and coated specimens.

Sample No.	Without coating HV	Coating thickness (30 μm) HV	Microhardness improvement at (30 μm) %	Coating thickness (40 μm)HV	Microhardness improvement at (40 μm) %	Coating thickness (50 μm)HV	Microhardness improvement (50 μm) %
1	239.5	341.4	42.5	421.5	76	502.3	101
	250.4	335.2	33.8	432	72.5	505.6	102
	260	333	28	411	58	509	95.7
	254	328.5	29.3	430.2	69.4	498.9	96.4
2	259.7	321	23.6	427.3	64.5	492.1	89.5
	288.8	343.3	18.9	438	51.7	513	77.6
avg.	258.733333	333.733333	29	426.6667	65	503.4833	94.6

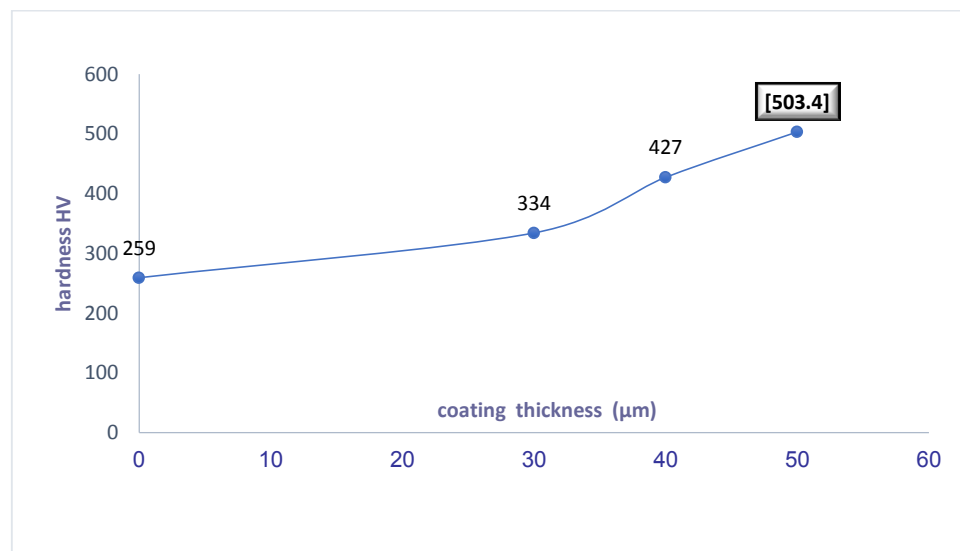


Figure 7. The microhardness value with coating thickness.

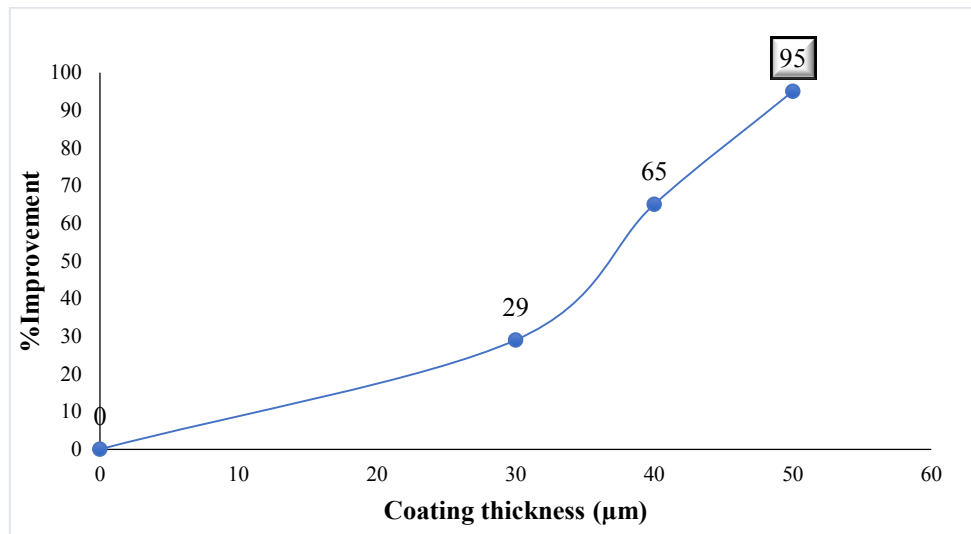


Figure 8. Improvement ratio in microhardness with coating thickness.

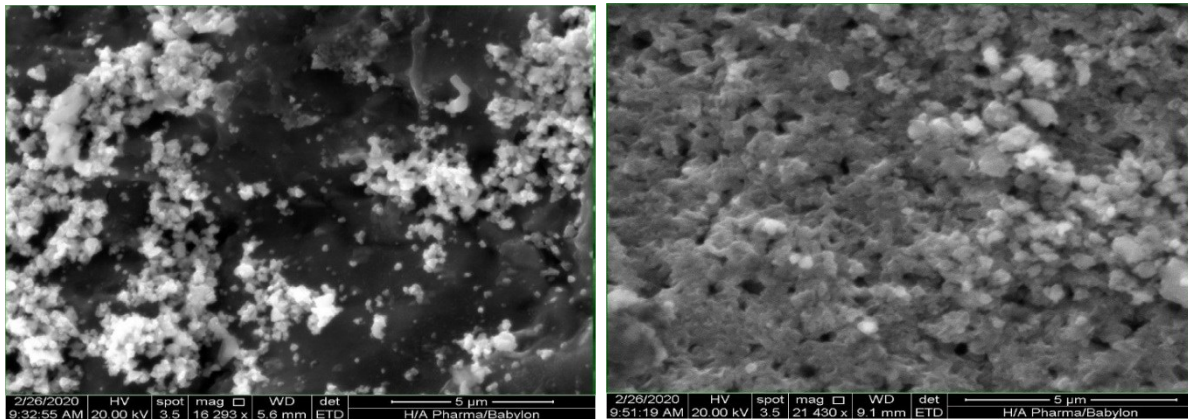


Figure 9. Tungsten carbides (WC) compound with a dense clumping.

3.2 Results of the impact test

The maximum applied impact energy on a sample coated with a layer of 50 μm thickness was 352 J; however, the maximum applied impact energy on samples without coating were capable where the average value of impact energy was 258.7 J, as presented in Table 3. The results showed that the rate of improvement reached 36%. Thus, it can be concluded that the tungsten carbide (WC) nanoparticles increased the cohesion of the particles, filled the cracks, and decreased the gap between them by increasing the layer, which in turn leads to absorb the energy resulting from the sudden force [19], as shown in Figures 10 and 11.

Table 3. The impact test results for coated specimens with different coating thicknesses.

Sample No.	Without coating (J)	With coating thickness (30 μm) (J)	With coating thickness (40 μm) (J)	With coating thickness (50 μm) (J)
1	284	328	356	348
2	232	336	324	332
3	260	288	368	376
average	258.7	317.3	349.3	352
Improvement %		22.7	35	36

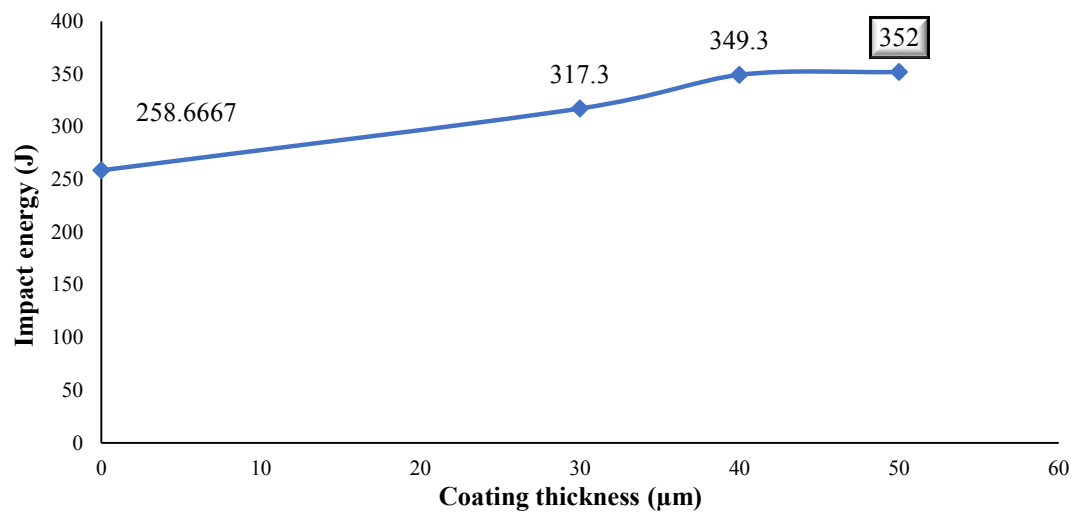


Figure 10. The impact test results for uncoated and coated specimens.

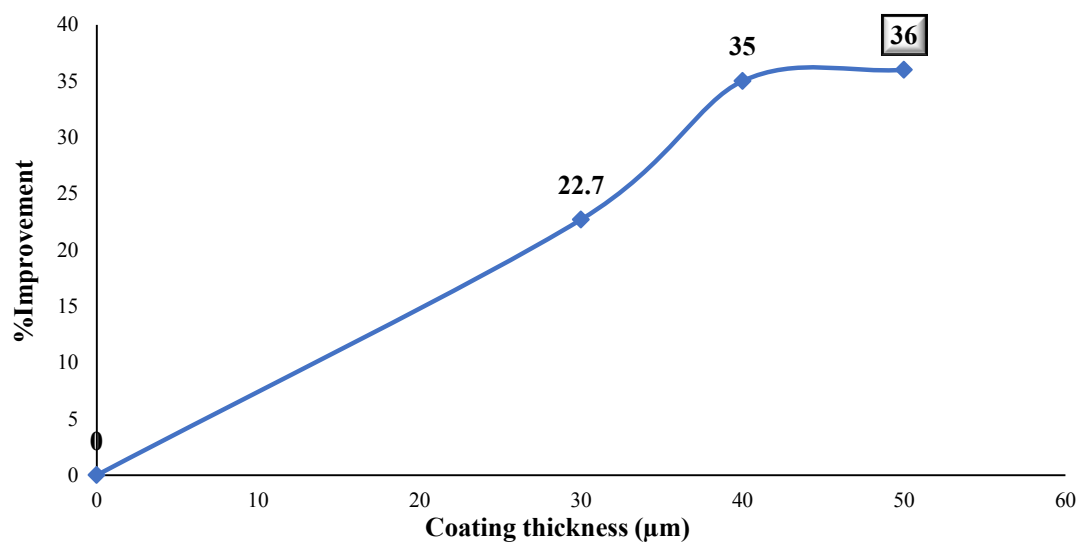


Figure 11. The relation between coating thickness and improvement in the impact toughness.

3.3 Scanning electron microscope (SEM) image analysis

The thickness of the coating layer of the samples was calculated at different coating times by SEM testing. The image J soft program was used to measure the coating thickness. It was found that the layers thicknesses of 30, 40, and 50 μm were achieved for coating time of 10, 20, and 30 sec, respectively, as shown in Figure 12.

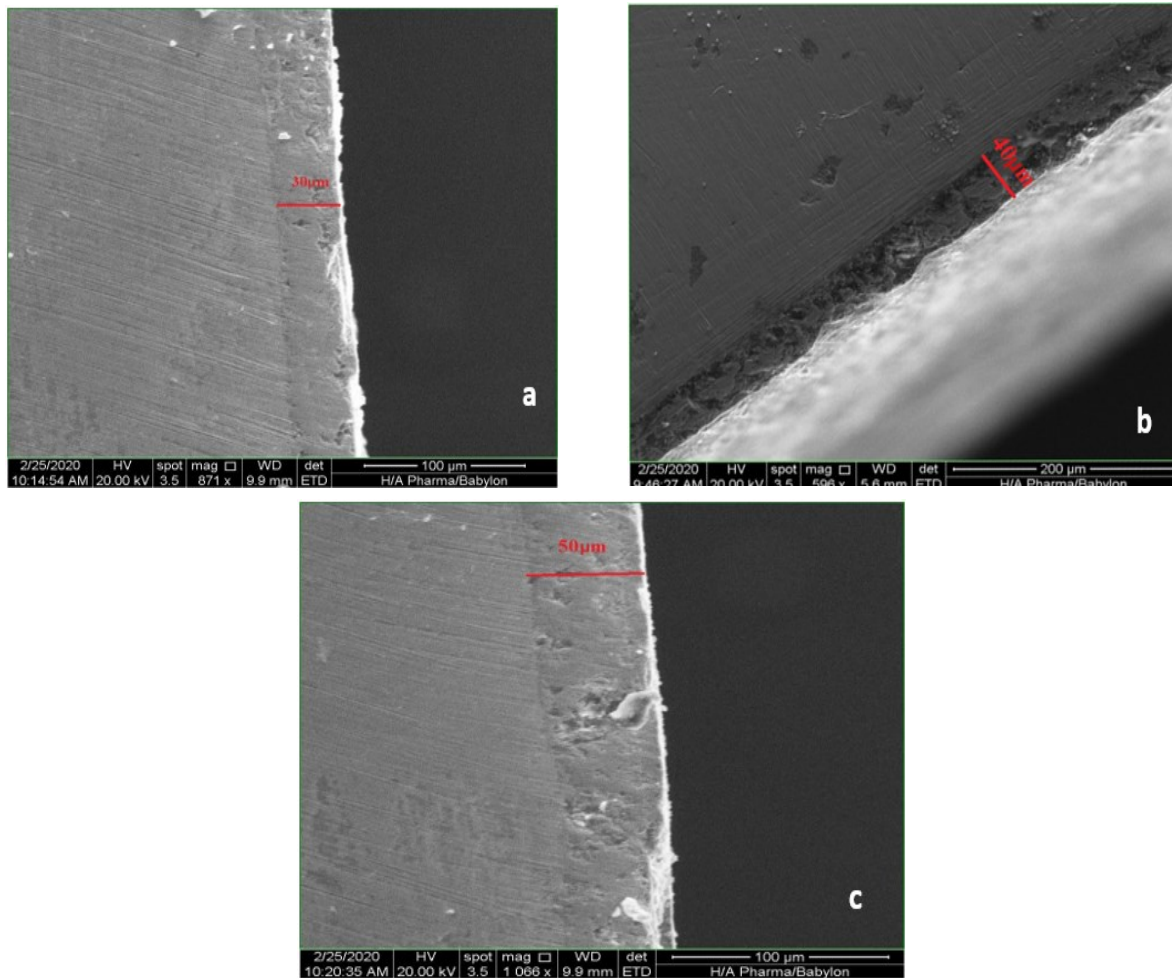


Figure 12. SEM image for coating thickness, (a) 30 μm, (b) 40 μm, (c) 50 μm.

4. Conclusions

Although the low carbon steel has low hardness and impact toughness, however, these properties can be significantly enhanced by coating the steel surfaces with nanoparticles of tungsten carbides (WC) using the thermal spray process (HVOF).

1. The microhardness increased when increasing the coating thickness. The best average ratio of improvement for microhardness reached 94.6% for a sample coated with a layer thickness of 50μm due to the high hardness of WC and good adhesion ability with a steel surface.
2. The impact resistance increased when increasing the coating thickness. The best average ratio of improvement for impact resistance reached 36% for a sample coated with a layer thickness of 50μm due to the high stiffness property of WC and good adhesion ability with a steel surface.
3. The coating of the steel surface with nanoparticles of WC limited to the thickness of 50μm as a coating layer, and when the layer thickness has been more than 50μm, that will cause flaking and failure in the coating layer on the steel surface.

5. References

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Acknowledgment

The authors would like to acknowledge the help offered by the Nanotechnology and Advanced Materials Research Unit (NAMRU) and Laboratories of Mechanical Engineering Department at the Faculty of Engineering University of Kufa, Iraq. The authors are thankful for the mechanical workshop in Kufa cement plant, Iraq.