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Effect of Parameters to the Coating Formation during Cold Spray Process

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Abstract – In this study, the effects of parameters such as substrate hardness, substrate surface roughness and stand-off distance to the coatings formation and properties of the coatings during cold spraying process were examined. For this purpose, coatings were deposited onto the copper substrate with using of commercially available copper powder. Substrate hardness of 55 HV, 107 HV and 140 HV were obtained by heat treatment and deformation hardening methods. Different substrate surface roughness was obtained by using of SiC emery papers which have different grits and stand-off distance during cold spray process was manipulated as 5, 10, 20 and 30 mm. After the production of the coatings, characterisation procedures were performed by microstructural observations which are optical and scanning electron microscope surveys, porosity concentrations, coating thickness and hardness measurement.

***Keywords*:** Cold spraying, coating, copper, spraying parameters

1. Introduction

Cold spraying is a new coating technique that was developed by the Russian scientist Anatolii Papyrin and his colleagues in the mid of 1980s and has been rapidly developing during the past two decades [1-3].

In this process, small particles (usually 1–50 μm in diameter) are accelerated by a supersonic jet of compressed gas at a temperature that is always lower than the melting point of the material, and then a coating occurs through the intensive plastic deformation of particles impacting on a substrate in solid state [1,4].

The low temperature in cold spraying process compared with conventional thermal spray processes enable metallic coating to be formed oxygen-free or little oxidation after spraying [5].

In the cold spraying process, the velocity of the sprayed particles is regarded as a main parameter extremely influencing the coating formation. In this respect, previous studies have been made to investigate various spray parameters with regards of its effect on particle velocities [6].

Even though there have been a great number of studies relating to the particle velocity, only few surveys concentrate on the remarkable effect of substrate hardness, substrate surface roughness and standoff distance on the particle deposition. One of the concerned studies was conducted by Shuo Yin et al [5], which suggested that substrate hardness has some effects on the deformation behaviour of the subsequently incident particles and it plays an important role when the formed coating is thin.

C. Zhang [7] and his colleagues have investigated the effect of standoff distance on coating deposition characteristics in cold spraying and they have found that the standoff distance influences deposition efficiency and coating thickness while it has little effect on coating microstructure and microhardness.

The other parameter is called by substrate surface roughness affecting cold spraying technique was carried out by Changhee Lee [8] and his colleagues. Copper powders were deposited on smooth and grit-blasted copper and aluminium substrates and characterized through scanning electron microscopy and Romulus bond strength analyser. They have mentioned that the deformation and bonding were higher for the roughened substrates than that of smooth.

The aim of this study is to investigate the effects of selected parameters on the coating formation during cold spraying process. Substrate hardness, substrate surface roughness and standoff distance were changed and other ones (inlet pressure of process gas, powder feeding rate, beam distance, traverse speed, process gas temperature and number of pass) were fixed during cold spraying process. The effects of the selected parameters on the coating quality were evaluated in terms of microstructures of the coatings, thickness of the coatings, porosity levels and coatings' hardness.

2. Experimental procedure

During the production of the coatings, commercially available spherical copper powders which has an average particle size of 10μm and a purity of 99.9% were utilized. High purity copper substrates which has a hardness of 120 HV were used. To investigate the effect of substrate hardness on coating formation, three substrates having different hardness values were obtained via various processes. For 107 HV substrate hardness, copper samples were heated up to 275 ºC for 1 hour and quenched in water. Another copper substrate which has a hardness of 55 HV was obtained by holding of a sample in 285 ºC for 1 hour and cooled to room temperature in furnace. Copper substrate which has a hardness of 140 HV was obtained with 85% deformation of the samples via compression test.

Four substrates having different surface roughness was obtained via grinding of the substrate surface with 80, 120, 400, 2500 grit SiC emery paper to investigate the effect of substrate surface roughness on coating formation. After the grinding operations substrates which have surface roughness of 1,7± 0,02 µm, 1,09±0,15 µm, 0,46±0,02 µm and 0,06±0,02 µm were obtained.

To examine the effect of stand-off distance on coating formation during cold spraying process 5, 10, 20 and 30 mm stand-off distance values were used during coating processes.

Microstructural characterizations were performed by microscopic examinations which were carried out on the polished cross-sections of the coatings by a Leica optical microscope and Hitachi TM-1000 scanning electron microscope (SEM).

Coatings' thickness and porosity concentrations were measured by utilizing CLEMEX image analysis software which is attached to the Leica optical microscope by using the optical microscope images of the coatings. Five different measurements were performed to determine the average coating porosity percentage.

Hardness of coatings was measured by a Shimadzu HMV microhardness tester on the polished cross-sections of the coatings with a Vickers indenter under a load of 200 g and at a dwell time of 10 s. The average of 20 successful indentations was taken as the coatings' hardness.

3. Results and discussion

3.1. Effect of substrate hardness

SEM micrographs of the coatings which were produced onto the substrate with different hardness are shown in Fig. 1. When we examine the coating structure, no discontinuity at the substrate coating interface but porosities in the coating exist at the upper layers and porosity concentration decreases with the increasing of substrate hardness (Fig. 2a). This phenomenon can be explained by the coating formation during cold spray process. It is strongly depends on the deformation of sprayed particles. In the case of the harder substrates, initial sprayed particles and the formed coating almost absorb all the kinetic energy resulting in the large deformation of the particle and slight deformation of the substrate. But in the case of the softer substrate, the kinetic energy of the sprayed particle partially contributes to the substrate deformation, which leads to lower compression ratio or slighter particle deformation compared to the case of the harder substrate. Clearly, the substrate material significantly affect the particle deformation degree which influences coating properties. In terms of the coating, increasing of the substrate hardness from 55 HV to 107 HV significantly affect the coating thickness and porosity concentrations but further increment in hardness does not cause remarkable changes (Fig. 2a and 2b). Furthermore, coating hardness changes with the substrate hardness are given in Fig. 3. As a results of the coating microstructure and the deformation rate of the sprayed particles which is discussed above, coating hardness is directly related to the substrate hardness.

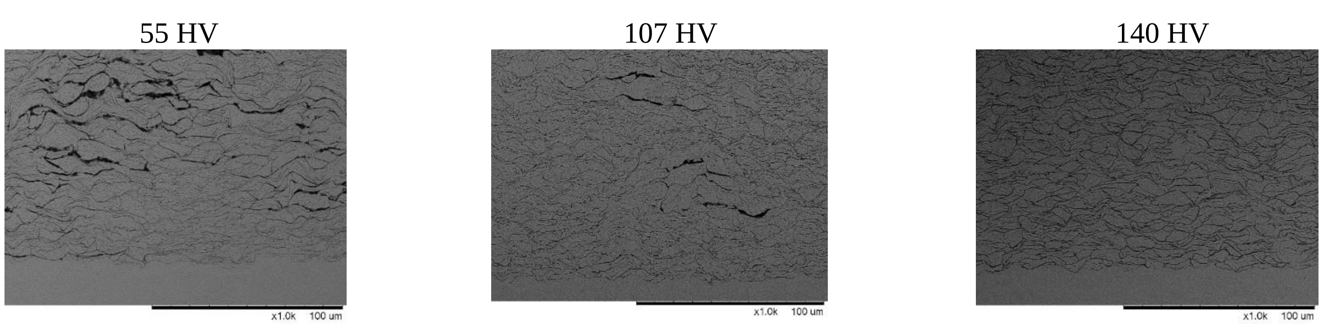
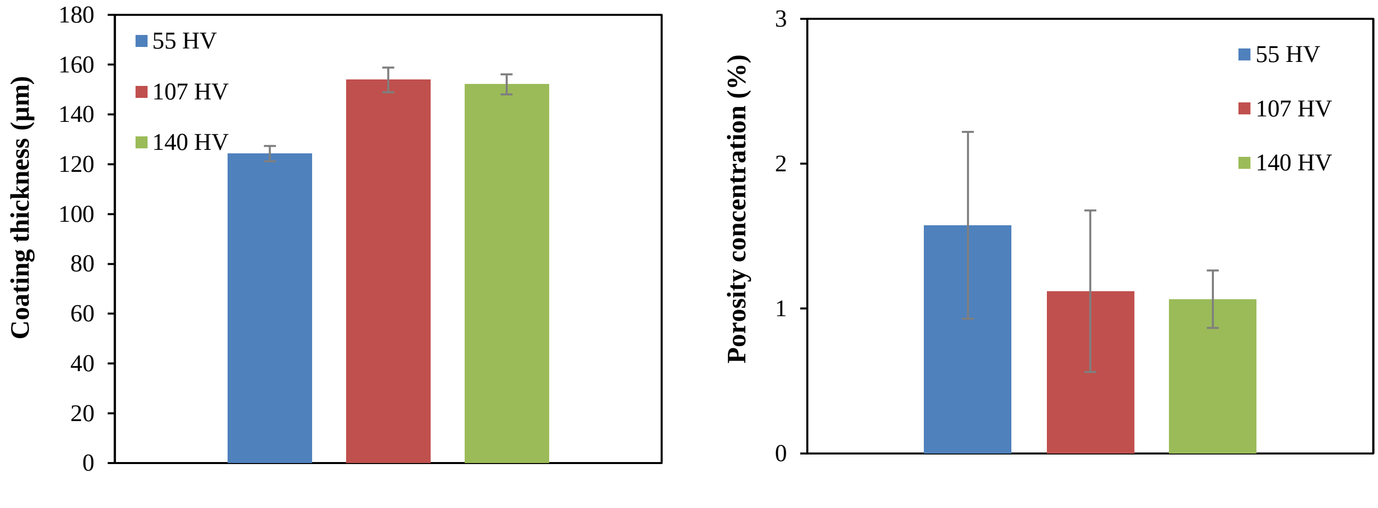


Fig. 1: SEM images of the coatings produced on the substrate with different hardness.



(a) (b)

Fig. 2: (a) Substrate hardness-coating thickness relation, (b) Substrate hardness-porosity concentration relation.

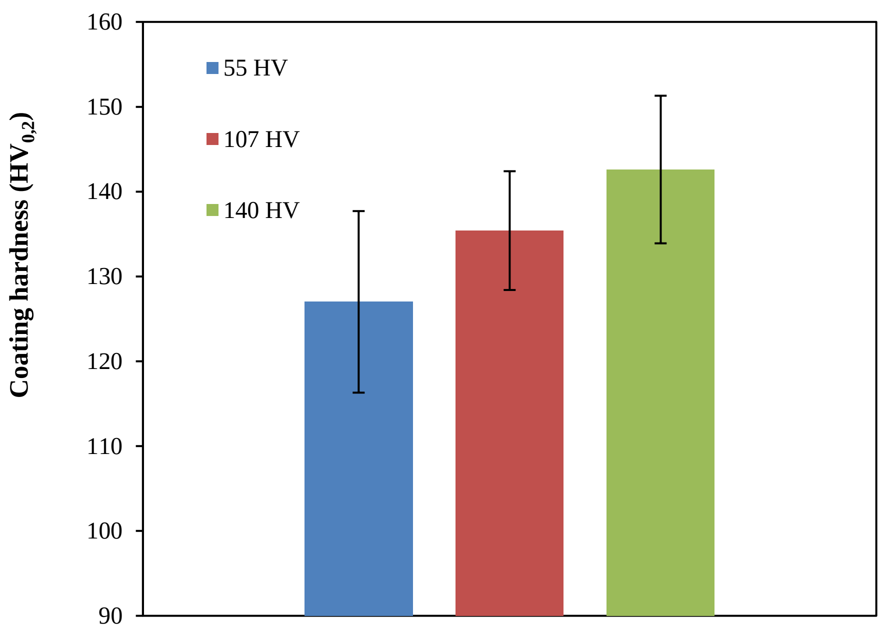


Fig. 3: Substrate hardness-coating hardness relation.

3.2. Effect of substrate surface roughness

SEM observations of the coatings produced onto the substrates which have different surface roughness are illustrated in Fig. 4. It is understood from the images that coatings successfully adhered to the substrate surface and any discontinuity cannot be detected at substrate surface interfaces for all the cases. Thickness of the coatings were given in Fig. 5a and it increases with the increasing of surface roughness up to the 1.09µm. This condition can be explained by the reduction of critical velocity by the increasing of surface roughness up to specific value. During cold spray process particles must deform which enables the interlocking of particles on substrate surface. Increasing of surface roughness can be decrease the critical deformation rate of the sprayed particles. On the other hand porosity concentration is the lowest for surface roughness of 0.46µm (Fig. 5b). Hardness of the coatings were given in Fig. 6 and it is directly related to the porosity concentration of the coatings.

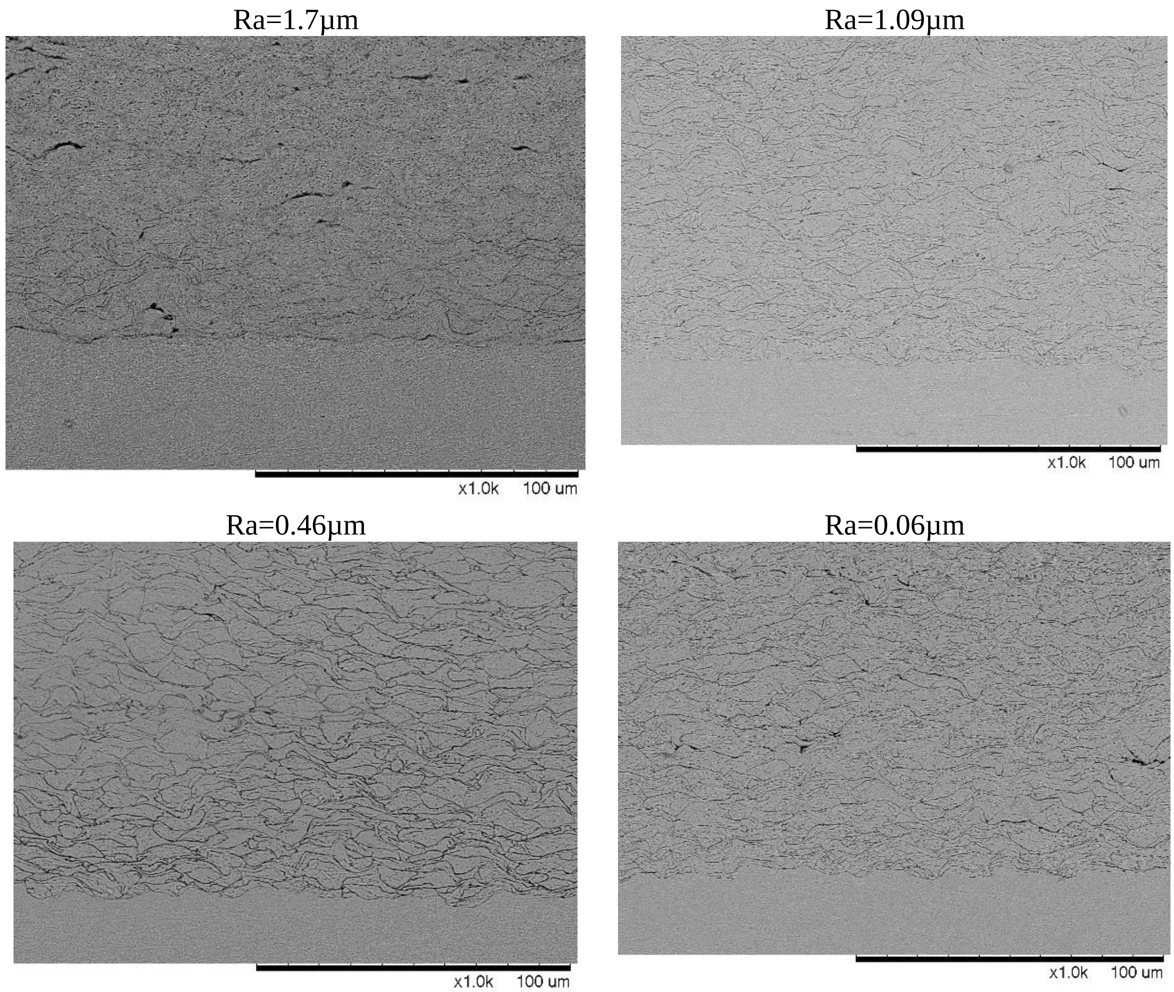
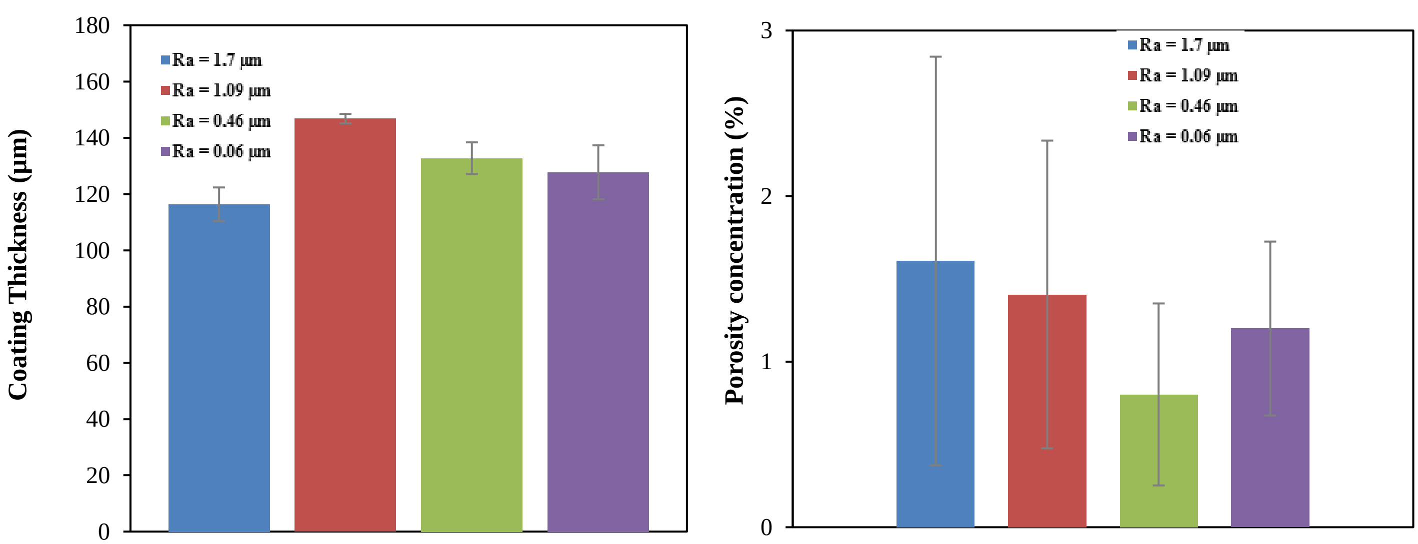


Fig. 4: SEM images of the coatings produced on the substrate with different surface roughness.



(a) (b)

Fig. 5: (a) Substrate surface roughness-coating thickness relation, (b) Substrate surface roughness-porosity concentration relation.

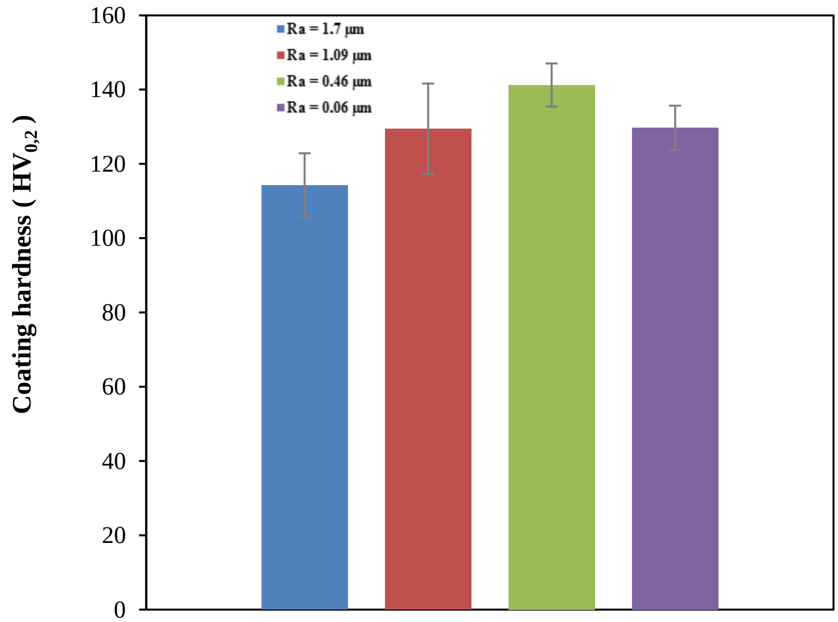


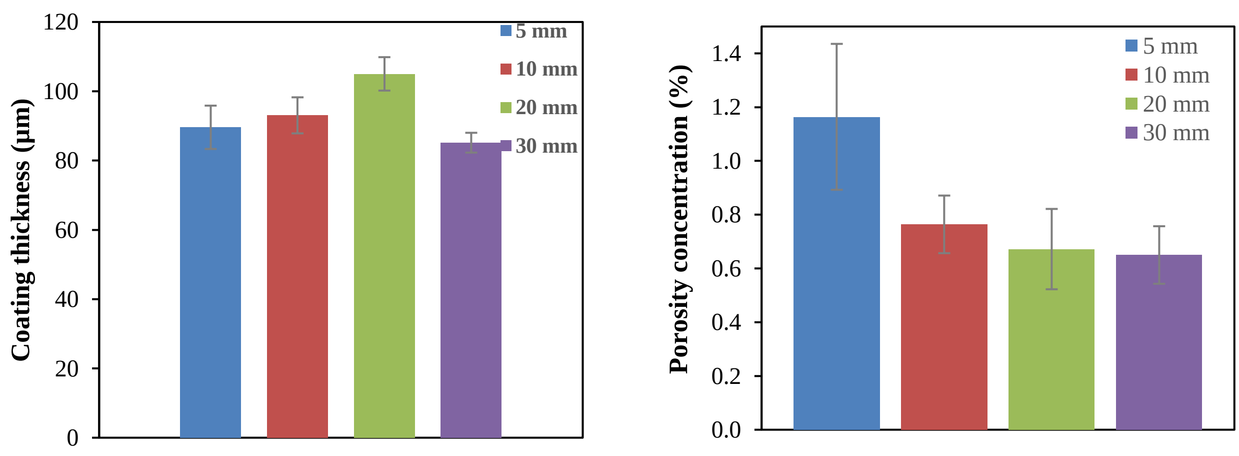
Fig. 6: Substrate surface roughness-coating hardness relation.

3.3. Effect of standoff distance

In cold spray process, the most important factor which affects the coating formation is the critical particle velocity and this velocity is dependent on the particle properties such as density and size. During cold spray process, acceleration of the particles continue when they exit from the nozzle. In that respect, stand-off distance is very important and this distance must be optimized. When the stand-off distance is than critical value, shock waves occurs on the substrate surface which causes the reduction in velocity. Otherwise, the distance higher than the critical value, particles' velocity decreases.

In our study, different stand-off distances were tried to determine the optimum value. SEM images of the coatings produced by using the stand-off distance which are 5, 10, 20 and 30 mm were given in Fig. 8. It is clearly observed that coating structure is similar for all the cases but there is a disintegration at the substrate/coating interface of the sample which is produced with the stand-off distance of 5 mm. This result can be related to the shock waves occur on the substrate surface which reduce the velocity of the particles and inhibit the reaching of particle velocity to the critical value.

Coating thickness and porosity concentrations were given in Fig. 7. Increasing of the stand-off distance up to the 20 mm increases the coating thickness and reduces the porosity concentration. Furthermore, hardness of the coatings which was given in Fig. 9 increases up to this level.



(a) (b)

Fig. 7: (a) Stand-off distance-coating thickness relation, (b) Stand-off distance-porosity concentration relation.

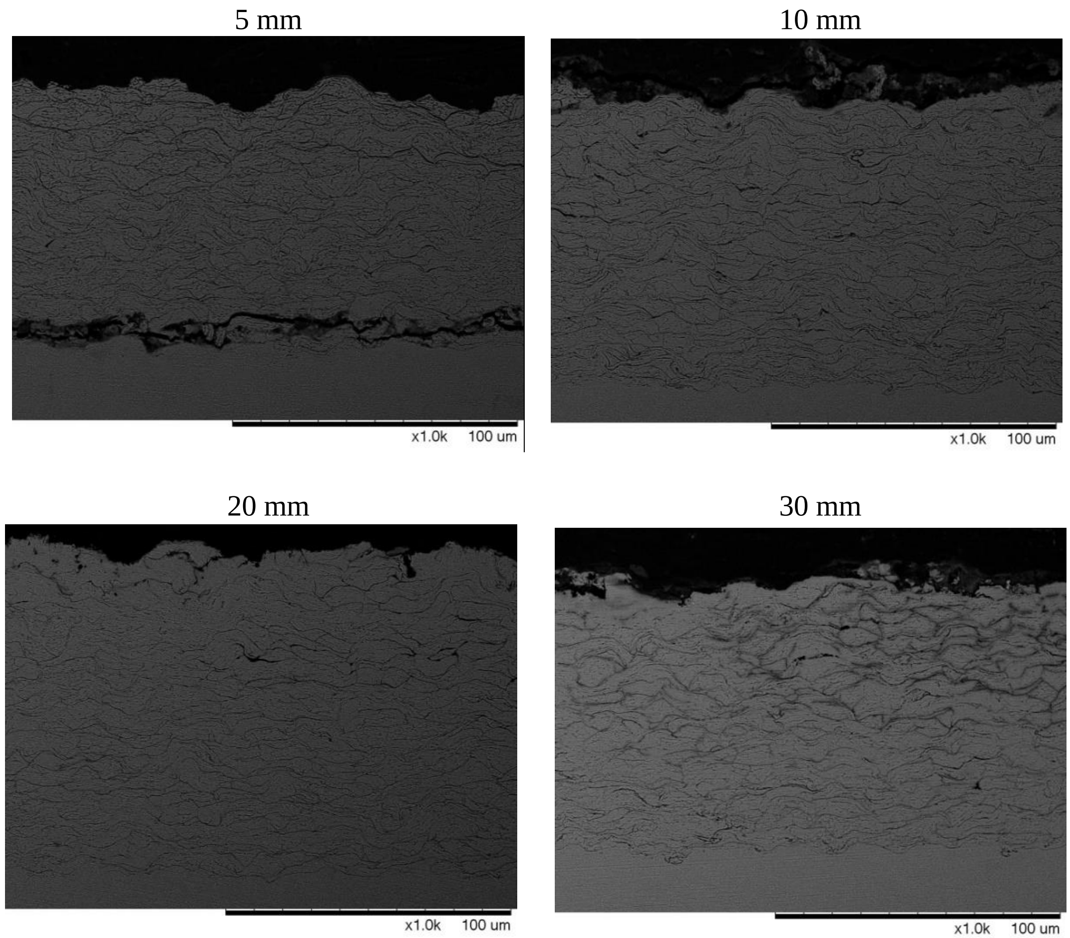


Fig. 8: SEM images of the coatings produced on the substrate with different stand-off distance.

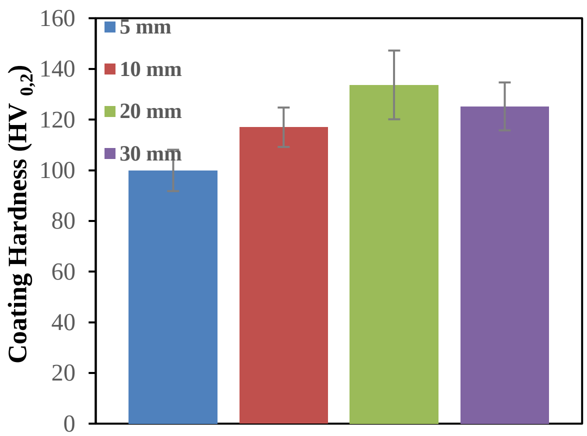


Fig. 9: Stand-off distance-coating hardness relation.

4. Conclusion

As a conclusion, coatings were deposited onto the copper substrate with changing the parameters such as substrate hardness, substrate surface roughness and stand-off distance during cold spraying process. According to the results of the examinations, increasing of the substrate hardness positively affects the coating properties in terms of coating thickness, porosity concentration and coating hardness. Surface roughness of the substrate up to 0.46μm causes increment in hardness and decreasing of porosity concentration. Additionally, in terms of the stand-off distance the best results were obtained for 20mm for all the cases.

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