Study of Some Mechanical and Morphological Properties as a Result of Adding Nickel-Aluminum to Silica by Flame Thermal Spray Method

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Abstract:

Samples are made with dimensions of 20 mm in diameter and 3 mm in height were manufactured from 316L steel plate, as the samples were prepared by the method of thermal spraying with flame, different percentages of Ni-Al and (0,5,10,15,20,25) % were taken. The base material of silica SiO2, thus forming cermet samples (ceramic + metal). The samples were sintered at a temperature of 900°C for two hours, and physical and mechanical tests were conducted, which obtained the best results at the optimal values from a spray distance of 16 cm, and sintering 900 °C, and the mixing ratio is 25%, and it was found that the hardness was (590Hv), while the lowest porosity was (4.5%), and the highest adhesion strength was (38MPa), while the lowest value for wear was (0.11), while the structural results were represented by examination of the microscope Scanning Electron (SEM) has shown that the best models of entanglement homogeneity are 25% of the Ni-Al reinforced metallic material.

Keywords: Cermet, Composites Material, Flame Spraying, Hardness.

Introduction:

Thermal spraying techniques have occupied an advanced position in the coating process, allowing the use of a wide range of materials, and composite materials; For the purpose of obtaining good physical and mechanical properties of the coating. Also, these techniques are generally considered one of the most important industrially used in surface coating processes for industrial requirements, especially in coating large pieces, with efficiency and high deposition rates [1,2]. These techniques require high precision and control, with coating parameters and conditions such as material feeding rate, air force, and distance between the spray gun and the base; For the purpose of obtaining coatings with good adhesion strength, as well as high structural and mechanical properties [3]. The criteria adopted for studying the efficiency of the coating layer are the tests of adhesion, porosity, oxidation resistance to high temperatures, thermal stability, mechanical hardness, as well as the homogeneity of the microstructure layers to note the homogeneity of the microstructure layers. Homogenization Coating, and the absence of pores, or surface cracks [5,4]. The selection of cermet composite materials consisting of oxides of ceramic materials with high melting points such as Al_2O_3), SiO_2 or ZrO_2) with added elements of ferrous materials called cermet [6]. In recent years, researchers have made a great effort to use these composite materials on a large scale in many electrical and thermal applications, which give good insulation properties at high temperature ranges (Thermal Barrier Coating), especially in jet engines, marine engines, and gas turbines [7]. Composite materials are usually affected by the properties of the materials included in their composition, which include the matrix (Matrix) and the Reinforcing Phase [8]. The base material usually represents the continuous phase in the composite material, as it works on the cohesion of the reinforcing elements and materials, and linking the parts together. To form a coherent synthetic system that can produce good mechanical properties, including increased strength and lightness in weight, the production of composite materials has been made to be an alternative to traditional engineering materials such as: metals, alloys or polymers. As for the reinforcing materials, they work to strengthen the base material, and these materials may be ceramic, metallic, or polymeric, and they are of different shapes, and they may be in the form of powders, fibers or crusts [9,10]. The research aims to study the most important variables of thermal spraying with flame through repeated additions of nickel to a ceramic system and to know the extent of the effect of this system with those additions, which is a suitable application for treating cracks that appear in the turbine blades as a result of high-temperature fumes.

Material and Methods

Silica powder was used as the base material (Matrix), which is manufactured by (Metco) company and has a granular size (30-60) µm, which has good insulating properties as well as its resistance to wear at high temperatures. A binder manufactured by (Amdry) company was used, which consists of an alloy (Ni80 Al20) and has a granular size (40-50) µm, due to its good resistance to oxidation at high temperatures, and its homogeneity of fusion with good adhesion strength between the substrate bases. and layers of ceramic coatings. An alloy of stainless steel (316L-AISI) was used for the purpose of coating the cermet on it, then it was cut into discs with a diameter of (20 mm), and a thickness of (3 mm), and the alloy contains the weight ratios shown in Table (1) which shows the analysis Alloy elements with Xray fluorescence (XRF) element analysis device, supplied by (OXFORD) company, type (X-MET5000). A locally manufactured granular blasting device (Grit Blast) was used for the purpose of increasing the surface roughness of the samples, by using sand grains (SiO_2) with a diameter range of (0.5-1.5) mm, then placing the coating bases in the locally manufactured base holder. The best spray parameters were selected through a series of preliminary experiments; To ensure obtaining layers of coating with good adhesion strength and a certain thickness in order to qualify us to study the physical and mechanical properties of this type of ceramic coating. The most important variables for spray parameters that are relied upon to determine the type of coating are the distance between the spray gun and the bases, the spray angle, the roughness of the base layer, the percentage of the binder added to the base material of silica powder and the thickness of the coating layer. Table (2) shows the most important parameters of the spraying process, which were obtained through practical experiments.

Table (1) Analysis of Base Coating Elements.

Elements	Ratio %
C	0.03
Si	1.00
Mn	2.00
P	0.04
S	0.03
Cr	17.00
Mo	2.25
Ni	12.00
Fe	Rem.

Table (2) Parameters of the flame Thermal Spraying Process.

Oxygen – Acetylene Mix.	4 :0.7
Coating Distance	12cm
Rotation Number	4
Flame spray temp	≈ 3000 ˚C
Particle size of powder	(20-55) µm
Coating Time	(1- 2) min
Maximum Thickness Coating	(1-1.45) mm
Time between two spray	5 sec

Ceramite compounds were prepared by taking different percentages (0,5,10, 15, 20, 25) % of the nickel-aluminum bond after a series of experiments. It was added to the base material (SiO_2). Then the mixture was mixed well using an electric mixer for a period of (2hr). Then, a preliminary heat treatment of the cermetal composite powders was carried out before the coating process at a temperature of (100˚C) for a period of (30 minutes) using an electric oven of German origin containing a thermal controller. The coating process was carried out on the prepared bases by the thermal spray process by aflame. This method was used to paint all the prepared samples under study. A temperature of (1100˚C) was used for a period of two hours for the purpose of sintering the prepared samples because of its excellent effect on the results through a series of experiments.

Mechanical and Morphological Tests

1.Hardness Test

The Vicker's Hardness was measured with a Leitz wetzlar device, model (GMBH - D6330), manufactured by Wetzlar Germany. The microscopic hardness was measured for the samples that were coated and then the samples that were heat treated, after conducting preparatory processes of smoothing and polishing for these samples, and the effect used is pyramidal in shape, and the load used was constant for all samples which is 160gm) within (10 sec). The microscopic hardness was measured by extracting the average diameter and applying the following relationship [11].

$$H_v = 1.8544 \times \frac{P}{(d_{av})^2} \quad ....(1)$$

Where: Hv: Vickers hardness (gm/mm^2), P: shed load (gm), d_{av}: average impact diameter (mm).

2.Wear Test

The Amsler apparatus was used to measure the slip wear rate of some samples of the coated composite material. Whereas the Amsler device consists of an electric motor that rotates at a constant rotational speed of 190 rad/min and is connected to a gear set with the axis of fixing the sprayed sample. The (Disk on Disk) rule was used to test the amount of wear. The weight method was also relied upon to calculate the amount of loss in the coating material as a result of sliding wear.

The process was carried out by weighing the sample before entering the device and after leaving the device using a sensitive scale with a sensitivity of approximately (0.001gm), which has a single pan of the type (Metll H311). The sample is placed in the place designated for it in the device and it must be in direct contact with the hard disk of very high hardness, and under the influence of a constant load (100 N). [12] .

$$wear\ Rate = \frac{M_1 - M_2}{D} \quad ....(2)$$

Where: M1, The mass of samples before the test, M2, The masses of samples after the test, D, The distance traveled during the test .

Where: $D=2 r^{-} \pi . n^{-}$ ………………(3)

Where: r^{-}: The radius of the sample (20,mm), n^{-}: The number of cycles (calculated from the number of cycles in the examination device).

3.Adhesion Test

The adhesion of the coating layer was measured by using a tension device that reaches its maximum load (1.5 Ton) according to ASTM Standard Technical Specification (C 633) [13]. When conducting the examination, samples of the base material without coating were prepared with an equal number to the unsprayed samples and with the same standard dimensions, and chemical cleaning was carried out using alcohol for both the unsprayed samples and the sprayed samples, in order to get rid of the effects of pollutants that hinder the process of sticking the two pieces together, using an adhesive (Epoxy) to stick the two eyes together (sprayed and non-sprayed), then put a regular thin layer of adhesive on the surface of the paint as it covers the entire area of the paint and then press the two pieces together for about two hours, then put it in a dried oven for 24 hours) at a temperature of (50°C).) . It is taken into account, before conducting the tensile experiment, that the adhesion should be uniform, and that the applied force force when performing the examination is completely perpendicular to the surface of the coating, then a tensile load was shed for each test sample at a tensile rate (1 mm / min), and until failure occurs to the sample as it is recorded, the highest shed load, three readings were obtained for each model and averaged. The adhesion strength or the cohesion strength of the coating of the composite material was calculated from the following relationship [13]:

Adhesion Force= $\frac{F}{A}$ … … … … … …(4)

4.Porosity Test

The Archimedes principle of the Immersion Method was relied on in calculating the porosity ratio according to Standard Specification No. (ASTM - C 830) [121], which includes the following steps, namely, drying the samples of the composite material for half an hour using an electric oven (heraeus type) at temperature (75°C), then weigh the samples using a sensitive balance with sensitivity (±0.001gm), this weight is called (W_1), and immerse the samples in a container filled with distilled water for (24hr) then weigh the samples saturated with water, and heated to (100°C) and left to cool and then weighed and this weight is called (W_2), the weight of the samples while they are immersed and suspended in distilled water and this weight is called (W_3). The percentage of open pores (P_o%) can be calculated using the following relationship [14]:

$P_o \% = [(W_2 - W_1) / (W_2 - W_3)] \times 100$ …………(5)

As for the percentage of total pores (P_T%), it can be found from the relationship [14]:

$P_T\% = [1-(\rho_B/\rho_s)] \times 100$ …………… (6)

Where: ρ_B: represents the bulk density of the coating material, ρs: represents the density of the coating base material, and is calculated in the same way, and the bulk density of the coating material is calculated from the relationship [14]:

$\rho_B = [W_1 / (W_2 - W_3)] \rho_w$ …………(7)

ρ_w: represents the density of water (1gm/cm^3).

5.SEM Test

The process of testing samples of coated overlapping materials is carried out using a scanning electron microscope (SEM) of the type (TESCAN) and of the model of type (Vega III) manufactured by JICKY, where the scanning electron microscope is distinguished from optical microscopes in the use of electrons instead of light waves, as it gives a detailed and magnified three-dimensional image and the image is in black And white because it does not depend on light waves, and the samples to be examined are placed inside the vacuum column in the electron microscope through an inlet or a tightly closed stopper, as the samples of the device are coated with silver or gold in order to have electrical conductivity, because the microscope illuminates the samples by shedding electrons on it [15].

Results and Discussion

1. Effect of adding a binder on the hardness:

The effect of the mechanical hardness values of the coating layers, the cermet, before and after the procedure, the heat treatment, and the optimum spray distance (16cm) can be seen from Figure (1). It has been observed that at low reinforcement ratios, the hardness is low due to the high porosity at these ratios. However, when the bonding material is increased and reached (25%), the hardness will be of a high value where the porosity is the least possible, that The hardness values start increase. gradually due to increase in strength coating bonding and decrease porosity. Where, when the heat treatment was carried out (900 ℃) and for a time of only two hours, the hardness values became larger, which led to an improvement in the hardness values and thus an improvement in the properties of the coating layer as a result of the sintering and diffusion process that led to an increase in the strength Bonding between the coating layer [16].

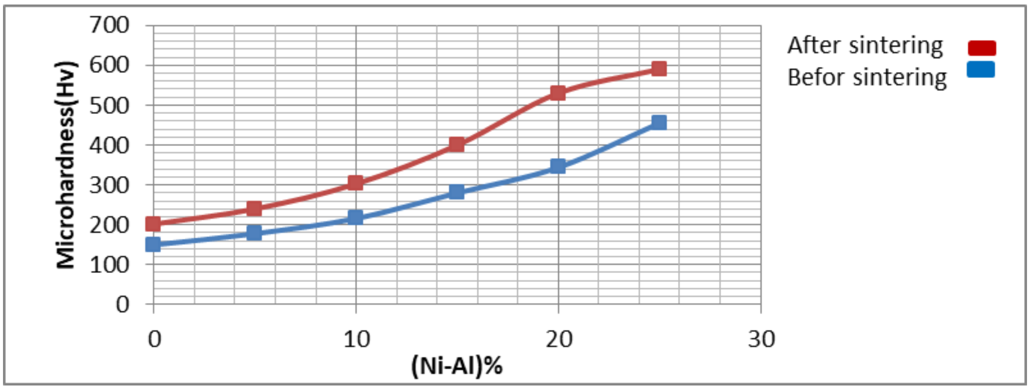


Figure (1) Effect of the binder on the micro-hardness before and after sintering.

2. Effect of adding a binder on the wear rate:

The wear is characteristics of surface of the material, Which can be explained as the loss of the material part of its surface to the metal due to the friction of the moving parts of the material. The wear rate was studied with the amount of applied load (25 N) and before and after the heat treatment. According to Figure(2),the additive has an effect on the wear rate, where we find that at low values of nickel-aluminum the wear rate is large and this is due to the weakness of the crystal structure of the coating. The high values of the addition, and the improvement of the mechanical properties of the coating layers and thus the absence of any plastic distortion, which led to an increase in the wear resistance and the coalescence of the particles with the surface. It was found that the wear rate with the increase of the binder additive. At these ratios, the lowest wear at 25N load was (0.32) before sintering, while the lowest wear after sintering was (0.11), which indicates the strength of the agglutination of crystal grains as a result of sintering at high degrees (900 °C) and this is what. It was found by the results of porosity, adhesive strength, and hardness [17].

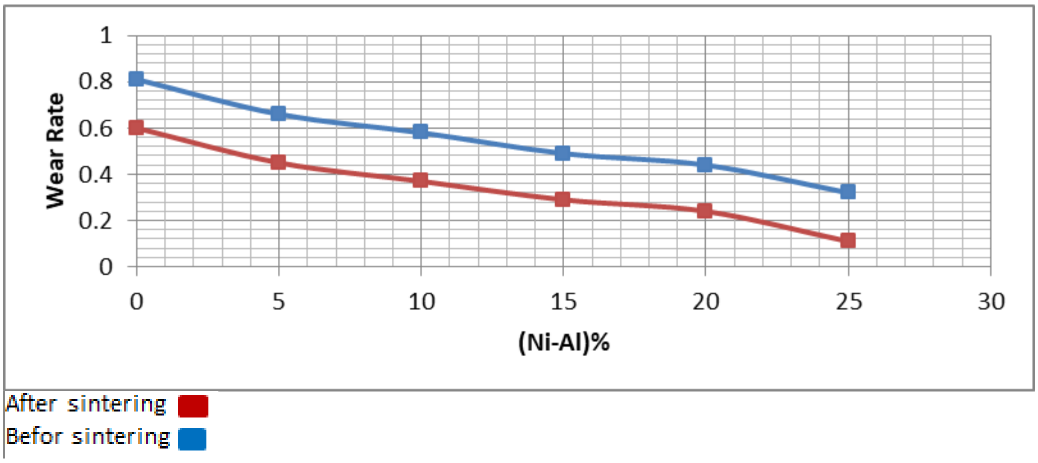


Figure (2) The change in wear values with the increase of the binder before and after sintering.

3. Effect of adding a binder on the Adhesion Force:

The values of the adhesion force are few when the distance between the spray gun and the base is close, then these values increase with the increase in the spraying distance until we reach the best and highest values of the adhesion force at the distance (16 cm), then the values begin to gradually decrease with the increase in the spray distance. Where the spray distance (16 cm) was relied upon after a series of experiments to obtain the best adhesive strength, and Figure (3) shows the relationship between the adhesion strength and the percentages of the added bonding material. The bonding material leads to a drop of the molten coating material reaching the surface of the base in a frozen form because the nickel and aluminum bind the granules together in a large way, and therefore its kinetic energy is low, and then the speed of its impact on the surface of the base is small, and it is not enough for the occurrence of coalescence or adhesion between it and the surface of the base. base surface, and thus the area of association with the base surface is weak. Whereas, the decrease in the spraying distance leads to a decrease in the adhesion force also due to the high porosity due to the high temperature of the molten material drops, which consequently leads to the occurrence of scattering of these drops in different directions [18]. (16 cm) This is consistent with what we obtained in the porosity and hardness tests, and in both cases before and after the thermal treatment of the models.

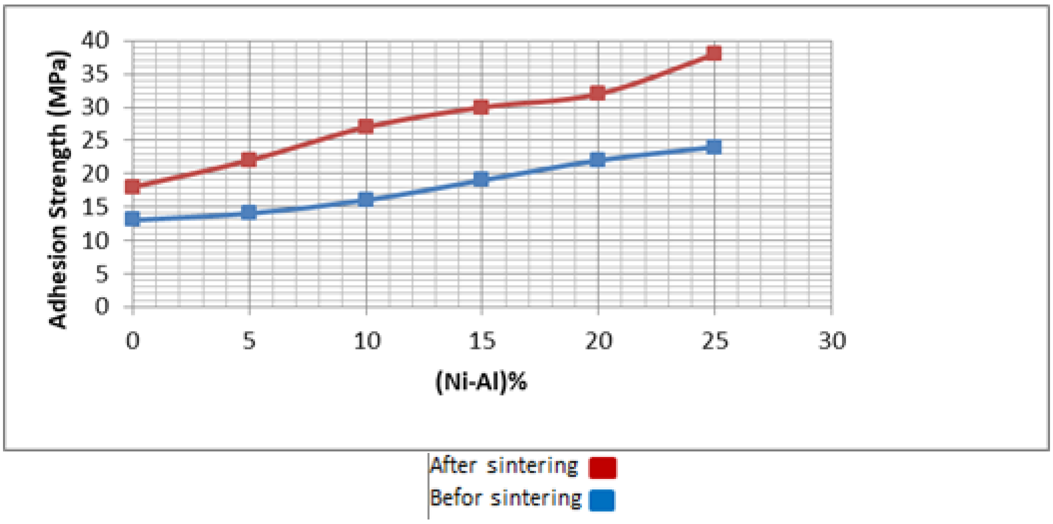


Figure (3) The change in the values of the adhesive strength with the increase of the binder before and after sintering

4. Effect of adding a Binder on the Porosity:

Through Figure (4), we notice that the porosity is very high when the proportions of the additive are few and then begins to decrease with the increase in the proportion of the binder (nickel-aluminum), and the spray distance is (16 cm) and with a heat treatment at a temperature of (900°C) starts Porosity decreased, this change in the porosity value is due to the formation of good bonding areas between the layers of the cermet coating due to the occurrence of sintering processes and diffusion of atoms through the transfer of atoms between them, and their attempt to close the pores when conducting heat treatment [19]. It is (16cm). The best heat treatment is (900°C), which is in complete agreement with the results of electron microscopy, adhesive strength and mechanical hardness.

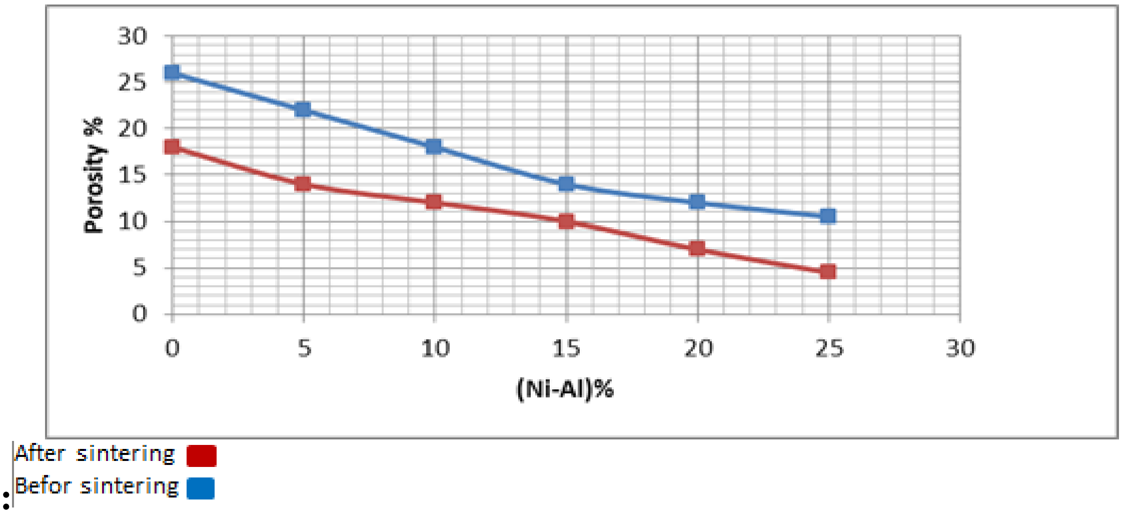
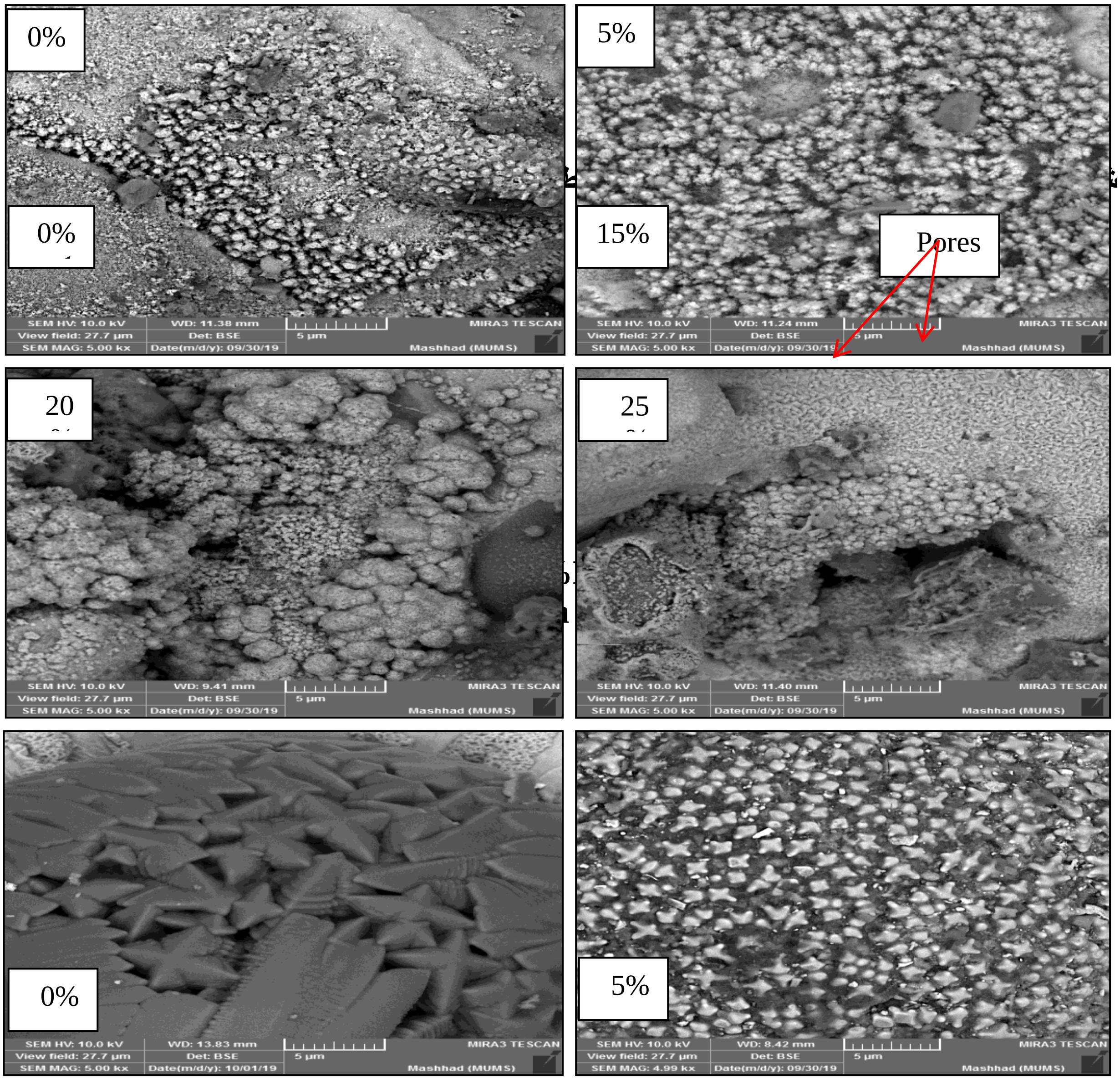


Figure (4) Porosity values change with the increase of the binder before and after sintering.

5. Scanning Electron Microscope Images changed as a Result of Adding(Ni-Al)%

Through the scanning electron microscope (SEM) images shown in Figure (5) before the thermal sintering process and in Figure (6) after the sintering process of the cermet compound and at (100, 5) µm, magnification for all samples, we note in the figure a cross-section image after the heat treatment (Sintering) at (900℃) that the bonding between the components of the compound is homogeneous but somewhat random, but the effect of heat is clear through the adhesion of the grains with each other with the spread of some surface defects to some extent with the pores in the microstructure. It is also noted that there are low-density and high-density regions, which led to the spacing of the elements from each other and their heterogeneity. We also find that the addition of the binder, which is nickel-aluminum with different values, led to a significant increase in the homogeneity of the coating layer and a decrease in the percentage of apparent pores[20], and the high thermal sintering ratio for a period of two hours had a significant impact on the improvement of the interface and the homogeneity of the ceramite materials and the improvement of physical and mechanical properties.



As for the figure (6) below, it gives the images of the scanning electron microscope of the sprayed samples and after performing the sintering process on them. It is clear from the figure the extent of homogeneity and the heat action that significantly reduced the porosity to a minimum [19], where we find that the best mixing ratio is (25%). Ni-Al), which, as shown, has cross-linked homogeneity between the sample components at a depth of (100)µm.

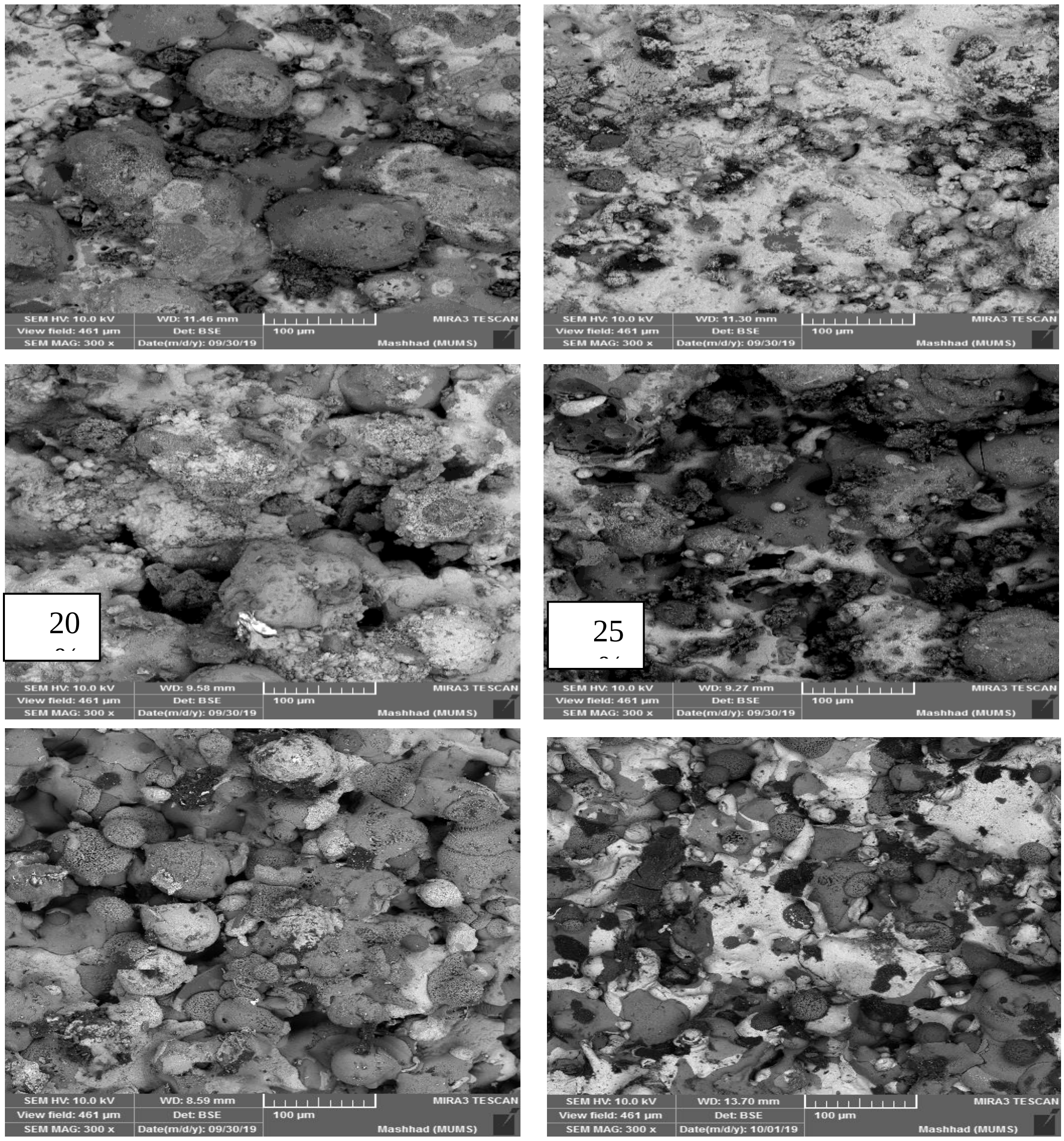


Figure (6) SEM images of (SiO_2-NiAl) coated models after thermal sintering with different ratios.

Conclusion:

The article is possibility of coating and mixing two materials, one of which is ceramic and represented by the base material of silica SiO_2 as well as the reinforcement material which is the metallic nickel-aluminum (%Ni-Al)by flame thermal spray method. 16cm and when sintering the samples at 900°C for two hours, it was found that the best mixing ratio was 25% NiAl. It was found that the best value of the micro-hardness at the above standard conditions was 590Hv, while the lowest obtained porosity was 4.5%, and the adhesive strength was 38MPa. In contrast to the high hardness, it was found that the minimum value of slip wear is 0.11.

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دراسة بعض الخصائص الميكانيكية والفيزيائية نتيجة اضافة النيكل- المنيوم الى السليكا بطريقة الرش الحراري باللهب.

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مستخلص البحث:
تم عمل عينات بأبعاد قطرها 20mm, وارتفاعها 3mm من صفيحة فولاذ نوع 316L حيث ان النماذج حضرت بطريقة الرش الحراري باللهب, تم اخذ نسب مختلفة من مادتي NiAl% وبنسب مختلفة %(0,5,10,15,20,25) وتم اضافتها الى المادة الاساس من السليكا SiO_2 وبذلك تكونت عينات سيرمتية (سيراميك+معدن), تم تلبيد العينات عند درجة حرارة 900°C ولزمن ساعتين, واجريت الفحوص الفيزيائية والميكانيكية والتي تم الحصول على افضل النتائج عند القيم المثلى من مسافة رش 16cm, وتلبيد 900°C , ونسبة مزج 25%, ووجد ان الصلادة هي (590Hv) , بينما كانت اقل مسامية هي (4.5%), واعلى قوة تلاصق (38MPa), بينما كان اقل قيمة للبلى هي(0.11), اما النتائج التركيبية والتي تمثلت بفحص المجهر الالكتروني الماسح (SEM) فقد بينت ان افضل النماذج تجانساً تشابكياً هي 25% من المادة المعدنية المدعمة Ni-Al.

الكلمات المفتاحية: سيرميت, المواد المتراكبة, الرش باللهب, الصلادة