Effect of Some Processing Parameters on Arc Sprayed Coating

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Abstruct

In this work, arc spray coating of 13% Cr-steel (BS403S17) has been used in repair of nodular cast iron journals. This study discusses the processing factors effecting the roughness, hardness,and wear resistance of coating produced by arc spraying. The studied factors are applied voltage, wire feed rate, spraying distance (distance between gun nozzle and substrate) and coating thickness. All coated samples were tested using pin on ring wear testing machine.

The final results showed that the best voltage in this application is between 28 and 30 V. With this voltage a reduction in wear rate of about 8% can be obtained. The research reveals that the wear rate decreases by 46% with increasing in wire feed rate from 68 to 122 mm/s and it is found that the best spraying distance is about 10 to15 cm to get a good coating surfaces with reduction by about 58% in wear rate. It is also approved that coating thickness has positive effect on reducing wear rate by 43%.

Keywords: arc sprayed coating,Cr steel,nodular castiron,roughness,hardness,wear resistance.

تاثير بعض العوامل التشغيلية على طلاء الرش بالقوس

الخلاصة

في هذا البحث تم استخدام اكساء من مادة الفولاذ الكرومي (13% كروم) في تصليح مساند من نوع حديد الصب العقدي .

ناقش هذا البحث دراسة العوامل التشغيلية المؤثرة على صلادة و خشونة و مقاومة بليان الاكساء المنفذ بطريقة الرش بالقوس الكهربائي, وتشمل هذة العوامل الفولتيةالمساطة ومعدل تغذية السلك ومسافة الرش وسمك طبقة الاكساء. وان جميع العينات المكسية قد تم فحص مقاومتها للبليان باستخدام فحص المسمار على القرص.

اوضحت النتائج النهائية للبحث بان احسن فولتية يمكن استخدامها لهذا التطبيق هي (28_30)فولت اذ انخفض معدل السوفان بمقدار 8% للسطوح التي تم اكساؤها .كما ظهر انخفاض بمعدل السوفان بنسبة 46% بزيادة معدل تغذية اسلاك الطلاء من 68الى122 ملم /ثا.كما وجد ان افضل مسافة للرش تكون بحدود (10_15)سم للحصول على سطوح اكساء جيدة مع تحسين في زيادة مقاومة السوفان بنسبة تقارب 58% .كذلك اثبت البحث ان لزيادة السمك الاكساءتاثير ايجابي في خفض معدل السوفان بنسبة 43%.

Introduction

Hard facing is the application of hard, wear-resistant materials to the surface of component by welding or thermal spraying for the main purpose of reducing wear [1].

Thermal spaying is a method in which metallic , ceramics, cermets, and some polymeric materials in the form of powder, wire, or rod are fed to a torch or gun with which they are heated to near, or somewhat above, their melting point . The resulting molten or nearly molten finely divided droplets of materials are accelerated in a gas stream by hot gas or plasma jets. And successively impacted on a (colder) substrate, leading to lateral flattening and rapid solidification and cooling onto a substrate, or onto a previously deposited layer. Arc spray process, also known as the cold process, uses two relatively ductile, electrically conductive, opposed charged wires which are arc melted. The molten metal on the wire tips is atomized and accelerated toward the substrate surface. Arc spray method has been used mainly in the fabrication of repair and anti wear coating on structures [2, 3].

Arc stability and therefore the structure and properties of the coatings are strong function of the processing parameters such as voltage, particle size, particle velocity, atomizing gas pressure and flow rate, nozzle designing, electrode size, electrode material properties and included angle between the two electrodes **[4, 5].**The temperature of a particle leaving the arc zone at the control volume exit can be obtained as follows **[6];**

$$T_{pi} = T_{pm} + \frac{V_{av} \cdot I_{av} - c_p \dot{m} (T_{pm} - T_{wi}) - q_{pi} \dot{m}}{c_p \dot{m}} \quad \ldots(1)$$

As shown in eq. (1), the particle temperature at the control voltage is inversely proportional with the wire feed rate.

Impregnation (or sealing) is used primarily to seal the interconnected porosity in thermally sprayed coatings prior to finishing, assist in reducing particle pullout from the surface during finishing for coating reliability with respect to the wear and corrosion behavior[7,8].

Kamachi et al **[9]** used electric arc spray of aluminum applied on SUS 304 stainless steel to improve its corrosion resistance. When the diffusion of aluminum occurs between the thermally sprayed coating and the steel substrate, the diffused layer does not remain porous.

The result shows that a reduction of the metals susceptibility to stress corrosion cracking and an extended service life were observed.

In the field of using coating for combat wear Stanton and weldl **[10]** developed a method of assessing adhesion and wear resistance, together with reference to the hardness value, of 13% Cr-steel coatings produced by the electric arc and oxygen / acetylene gas pistol. The result of adhesion test showed that in all cases where arc spraying was used failure occurred within the coating itself (cohesion failure).

Ahmed **[11]** studied the effect of distance, substrate preheating, substrate roughness and coating thickness on coating wear resistance. The coating is produced by flame spraying of iron base powder on steel substrate. And it was found that the best spraying distance is between 15 cm to 20 cm to get a good coating surface with the highest wear resistance. It was also proved that

increasing of thickness has an improving effect of decreasing the amount of wear.

Krisha et al [12] study feasibility experiments carried out with oxy-acetylene spray system using different tungsten carbide powders and powder feeding methods to evaluate the newly developed fused WC, synthesized by transferred arc thermal plasma method. The microstructure and phase composition of powders and coatings were analyzed by optical and scanning electron microscopy and X-ray diffraction. Coatings were also characterized by their hardness and abrasive wear. The results demonstrate that the powders exhibit various degree of phase transformation during the spray process depending on the type of powder, powder feed and spray parameters

Kulu et al [13] study enhancement of the wear resistance of some engineering materials by thermal sprayed coatings .Coatings of tungsten carbide based hard metal, nickel based self-fluxing alloy and composites on the basis of NiCrSiB alloy were deposited from these powder by the detonation gun, continuous detonation spraying, and spray fusion process. Solid particle erosion tests were performed on these coatings with silica abrasives of size in between 0.1 and 0.3 mm .Influence of the test variables and material parameters is discussed. Differences in the wear behavior are rationalized in terms of coating hardness and structure.

In the present work we study the process of repair of crankshaft journal of a vehicle by the method of electric arc spraying. The following parameters are practiced:

1. Arc voltage.
2. Wire feed rate.
3. Distance between gun nozzle and substrate.
4. Coating thickness.

The ultimate goal is to establish the effect of above parameters on coating quality, mainly expressed in term of hardness and wear resistance.

Experimental Work

Crankshaft journal of nodular cast iron is used as a substrate material. 13%Cr steel type 60E, wire of 1.6mm diameter is used as a coating material. To increase adhesion of sprayed coating a Ni-Al wire of 1.6mm diameter is used. Bearing shell is cutting to small element and used in wear test as a pin. The chemical compositions of all above materials are shown in Table (1).

Air dray phenol sealers are used after spraying and before surface finishing .A talysurf device is used to measure the surface roughness of the sliding surfaces (i.e. the coated journal and pin used in wear test).

Crankshaft preparation

The preparation of journal surfaces for the application of metal sprayed coatings is done on the crankshaft in the following methods:

a. cleaning crankshaft thoroughly. The part is heated, with soaking in a chemical solvent, to surface temperature of 300°C.These drives out the oil and foreign mater from oil holes.

b. mounting and locating crankshaft in throw-plates. Grinding to lowest limits, to reduce diameter of journal to 55mm.

c. cleaning up the journals with clean, sharp, medium grad emery cloth (grad 100).

d. plugging oil-holes with carbon sticks.

e. applying Ni-Al bond coat to surface of journal to a thickness approximately (0.05 to 0.1 mm)

Now the surface is completely prepared for apply 13% Cr-steel coating. Since the important factor for the successful bonding of sprayed metal is the time lag between preparation and spraying. This must be kept to a minimum.

Spray with 13%Cr-steel

The coating process is done by changing the following variables; applied voltage, wire feed rate, distance between the gun and the substrate and finally the coating thickness. According to these variations, the specimens were numerated and divided into four groups .The first group includes (5) journals .Each journal was coated with different applied voltage and keeping the other parameters constant as shown in table (2).

The second group includes also (5) journals. The same coating procedure is followed as in the first group except that the feed rate was used with variable values while the other variable were kept constant as shown in table (3).

Coatings of the third group were achieved with variation of the distance between the gun nozzle and work surface and keeping the other parameters constant as shown in table(4).

The fourth groups were coated with different coating thickness keeping the other parameters constant, as shown in table (5).

Testing

The coated journal is cutting from the repaired crankshaft and machined to the required size suitable for test, to describe the exact phases of coating material before and after the deposition, X-ray diffraction system was used.

Optical microscopy is used for basic study of coating structure and its bonding to substrate.

Vickers scale is used to measure hardness of the specimens. Pin-on-ring wear testing machine has been used during this work, which consists of an electric motor of power of 1.0 hp, 3-phase 380 V and angular speed of 1000 r.p.m with variable speeds from (0-1000) r.p.m. The test journal is fixed on the rotating shaft tightly by screw. While the pin is fixed vertically on the journal by a vertical arm and pin holder. The following relation is used [14];

$$K = \frac{\Delta m}{\rho . V_s . T} = \frac{m_1 - m_2}{\rho . V_s . T} \quad \text{.....(2)}$$

The following symbols will be used in the present work as well:

W : applied normal load=10 N.

Raj: surface roughness of the test journal=0.95 mm.

Rap:surface roughness of the pin =0.44mm.

Built-up samples of sprayed metal (3-4mm thick) wear cutting from the base. The sample is dried weighed and then immersed in water in such a way that all the open pores become filled. It is then weight, first immersed in the water and then in air.

Then:

$$\text{Bulk density} \quad \rho = \frac{W_a}{W_c - W_b} . D' \quad \text{....(3)}$$

Resulits And Discussion

Fig. (1a) shows the X-ray diffraction results for coating wire 13% Cr-steel before spraying process. It shows the presence of single iron phase type (α). After coating process other phase is produced in addition to iron phase, as shown in Fig. (1b), such as the presence of iron oxide (Fe_2O_3).This oxide is nurtured on the particle during its flight from the gun to the substrate and after deposition.

Effect of studied parameters on hardness

Figure (2) shows the relationship between the applied voltage and Vickers hardness.

It is clear from figure that the hardness is increased in the voltage range between 26 and 29 V then starts to decrease with increasing voltage. This behavior can be attributed to the effect of applied voltage on melting condition in the arc zone. The voltage range 26 -29V has maximum arc stability as compared with other range. The stability of arc gives uniform and consistent coating, with minimum structural defects (e.g. void, large porosity) and good compact between deposited particles. Thus the hardness is increased with this range. While the structural defect of coating produced by arc spraying with lower stability of the arc for the other ranges, result in lowering in hardness values.

The relation between wire feed rate and hardness is shown in figure (3). It is indicated that hardness is increased with increasing this parameter within the range of 68 to 122 mm/s. The high feed rate promotes coarse particles of coating on substrate. These particles may have a higher penetration resistance to indenter of the hardness test. These lead to increase in hardness. These results are agreed with that obtained by **[15].**

It is illustrated from Fig. (4), that increasing the distance from8 to 24 cm, between spray gun and the substrate enhances the hardness. It is known that oxidation of coated layer is increased with increasing of spray distance **[16]**. The enhancement of hardness may be attributed to the increased hardness of coating materials oxide compared to the coating material itself.

The hardness is increased with the increment of coating thickness by a non-linear relationship. The increase in thickness makes the sprayed particles more compacts and decreases the amount of porosity **[11]**.This results in an increase in hardness, as shown in fig. (5), in this range from 1 to 2 mm.

Effect of studied parameters on wear

The effect of applied voltage on wear rate is shown in fig. (6).It indicates that with the increasing of voltage, there is a minimum wear rate range appears at the voltage of 29 volt, beyond which there is an increase in wear rate. This value is corresponded to the maximum hardness shown in fig. (2). 8% reduction in wear rate can by obtained. Since the surface hardness is often considered as an important property indicating resistance to wear **[10]**, the behavior of wear is appeared to be the inverse of the behavior of hardness

Fig. (7) shows the relationship between wire feed rate and wear rate. It is clear that with increasing of wire feed rate, the wear rate varied in an inverse way to the hardness, see fig. (3), i.e. the wear rate is lowered in linear relationship with increase wire feed rate. The reduction in the wear rate of about 46% is obtained.

The relation between wear rate and spray distance is shown in Fig. (8). It is obvious from the figure that the wear rate decreases with increasing of spray distance up to 15 cm, then it begins to increase with increasing in spray distance. The first behavior of the wear rate, i.e., decreasing stage up to 15 cm, can be attributed to the increase in hardness, as shown in fig (4), and good bonding of the sprayed particles. During the subsequent stage, i.e., with increase distance, there is still an increase in hardness but an increase in wear rate is also obtained. This behavior can be attributed to the increase in oxidation rate of sprayed particles, which result in

a thin layer of oxide. This layer hinders particles in interaction and thus results in the formation of interparticale pores and provides a path for crack propagation in the particle intermediate layer **[17].** Therefore the effect of inclusion and structural defects on the wear resistance is greater than the effect of hardness. On the base of this theory, the wear rate begin to increase when the spray distance is beyond about (15) cm. Fig. (9) shows the wear characteristic with different thickness of coating. It is clear that wear rate is decreasing with the increase of thickness. These results can be attributed to the rise in hardness and reduction in porosity and structural defect with the increase in coating thickness. This result is agreed with that obtained by **[11].**

Microstructure Analysis

A sample suitably prepared for metallographic examination reveals a heterogeneous mixture of sprayed material, oxide inclusion and pores, Fig. (10).

Fig. (11) shows the microstructure of the base material (crankshaft journal). Spheroid graphite weakens the metallic matrix to a lesser extent than flaky graphite. Thus, nodular cast iron possessing high strength (σ_u = 50 to 70 Kg f/mm^2) has very high ductility (δ = 10 to 20 %) which is much above that of gray cast iron **[18].**

Fig. (12) shows the microstructure of coating material with the substrate. The deposit is bonded to the substrate by adhesive forces and to itself by cohesion.

Conclusions

1: The best voltage range is between 28 and 30 volts which give a reduction in wear of about 8%.

2: The increase in wire feed rate lead to an increase in hardness and cause a reduction in the wear rate of about 46%.

3: The results show that there is an increase in coating hardness with increasing spraying distance within the range of 8 to 24 cm. The best distance for maximum wear resistance is about (10_15) cm which gives a reduction in wear of about 58%.

4: Increasing the coating thickness results in an increase in both hardness and wear resistance .With increasing coating thickness from 1 to2 mm a reduction in wear rate about 42%is obtained.

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c_p ,c^-_p=Specific heat of the particle over and under the melting point.

$D^/$=density of immersion liquid at temperature of test

V_{av} = Mean loading voltage.

I_{av} = Mean loading current.

$\dot{m}$ = Wire feed rate.

m_1: weight of journal before test.

m_2: weight of journal after test.

T_{wi} = Initial temperature of the wire.

T_{pm} =Melting temperature of the wire or particle.

T : sliding time =7200(sec).

WA=weight of dry test piece.

W_b=weight of test piece soaked and suspended in the immersion liquid.

W_c=weight of test piece soaked and suspended in air.

q_{pi} = Latent heat of fusion.

V_s: sliding speed =2.885(m/s)

ρ: bulk density of coating =0.0067 (g/mm^3).

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Table (1): Chemical composition of used materials.

Element Sample	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	V	Fe
Crank-Shaft	3.9	2.08	1.13	0.04	0.32	0.21	0.36	0.11	0.20	0.01	Rem
Coating Wire	0.33	0.39	0.72	0.04	0.02	13	0.05	0.29	0.07	0.07	Rem
Pin	0.07	_	0.38	_	0.02	_	0.01	_	_	_	Rem.
Bond wire	Mn	Cu	Zn	Cr	Fe	Co	Mg	Al	Ni		
	2.27	0.04	0.11	0.07	13.74	0.26	1.08	5	Rem		

Table (2) coating parameters of first group

Journal No.	Coating thickness mm	Applied voltage V	Distance cm	Feed rate mm/s
1V	1.5	26	13	68
2V	1.5	28	13	68
3V	1.5	30	13	68
4V	1.5	32	13	68
5V	1.5	34	13	68

Table (3) Coating parameter of second group

Journal No.	Coating thickness mm	Applied voltage V	Distance cm	Feed rate mm/s
1F	1.5	28	13	68
2F	1.5	28	13	28
3F	1.5	28	13	95
4F	1.5	28	13	10
5F	1.5	28	13	12

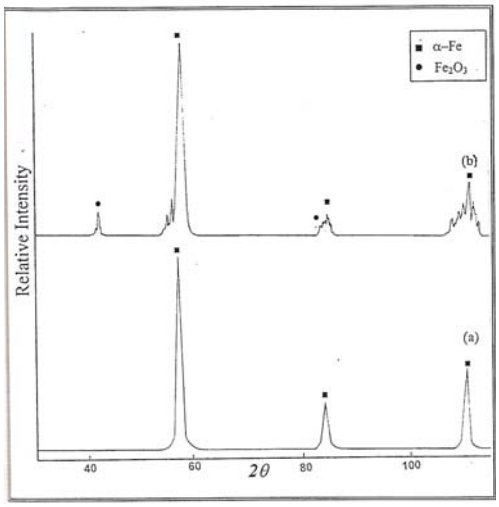
Table (4) coating parameters of third group.

Journal No.	Coating thickness mm	Applied Voltage V	Distance cm	Feed rate mm/s
1D	1.5	28	8	122.5
2D	1.5	28	12	122.5
3D	1.5	28	16	122.5
4D	1.5	28	20	122.5

5D	1.5	28	24	122.5

Table (5) coating parameters of fourth group

Journal No.	Diameter before coating mm	Diameter after coating mm	Coating thickness mm	Applied Voltage V	Distance cm	Feed rate mm/s
1t	56	58	1	28	12	122.5
2t	55.5	58	1.25	28	12	122.5
3t	55	58	1.5	28	12	122.5
4t	54.5	58	1.75	28	12	122.5
5t	54	58	2	28	12	122.5



b Coating on material after deposition.

a Coating material before deposition.

Fig. (1): X- ray diffraction results for coating wire 13%Cr.

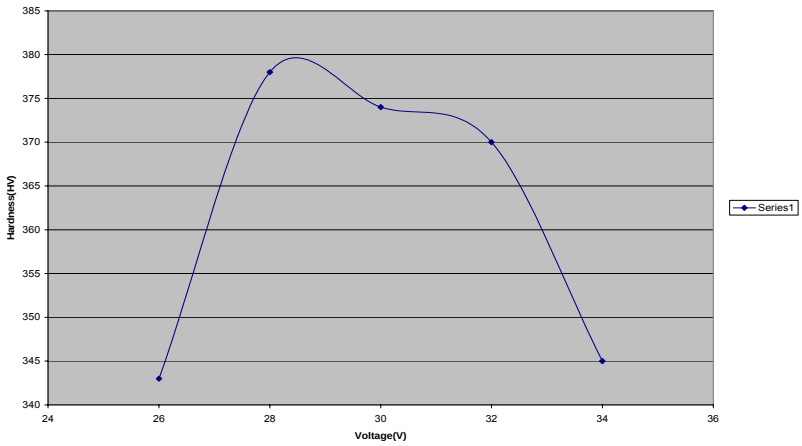


Fig (2) The relationship between the applied voltage and Hardness.
Coating thickness=1.5mm.Spraying distance=13cm.

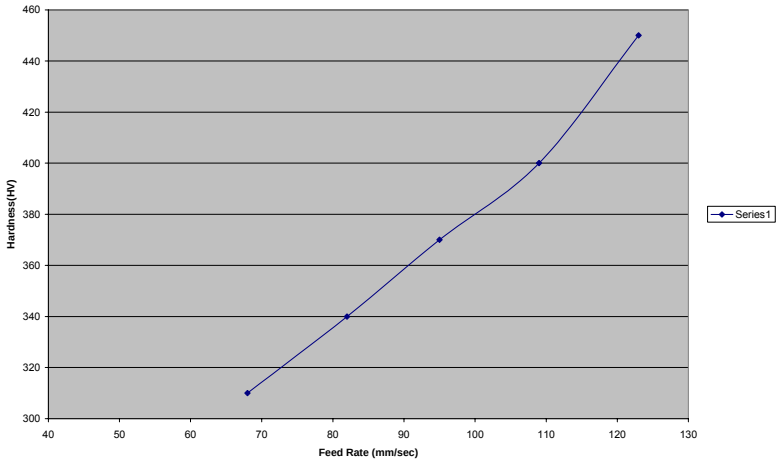


Fig (3) The relationship between the wires feed rate and hardness.
Coating thickness=1.5mm.Spraying distance=13cm.

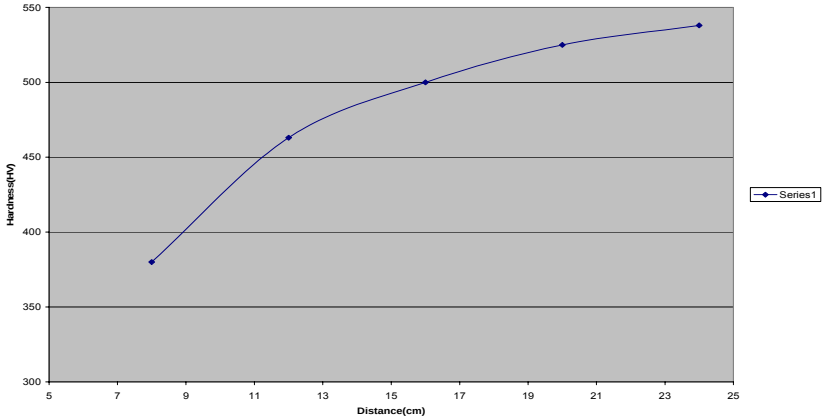


Fig (4) The relationship between the spray distance and the hardness.
Coating thickness=1.5mm

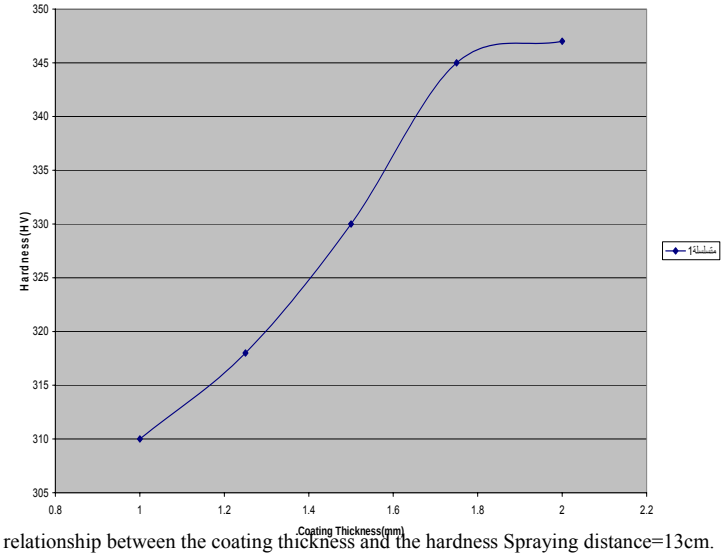


Fig (5) The relationship between the coating thickness and the hardness Spraying distance=13cm.

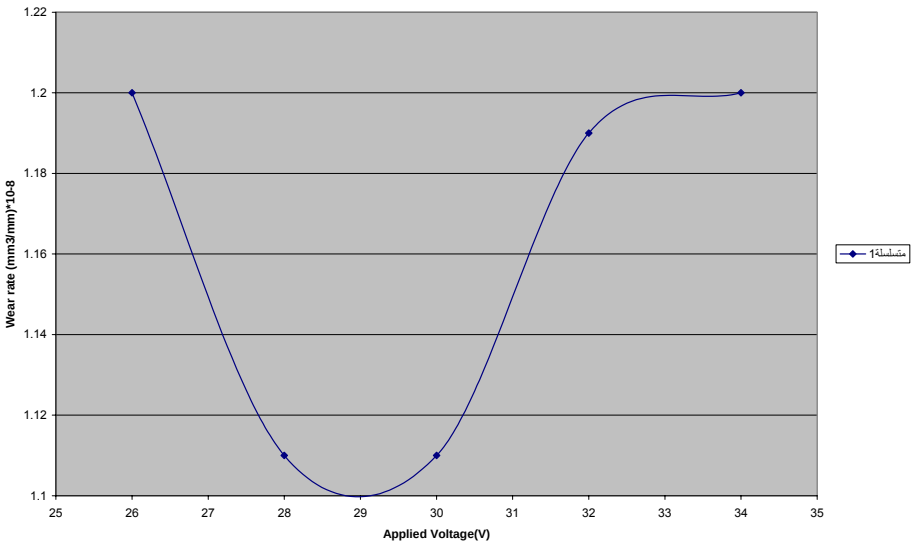


Fig (6) The relationship between the applied voltage and wear rate.

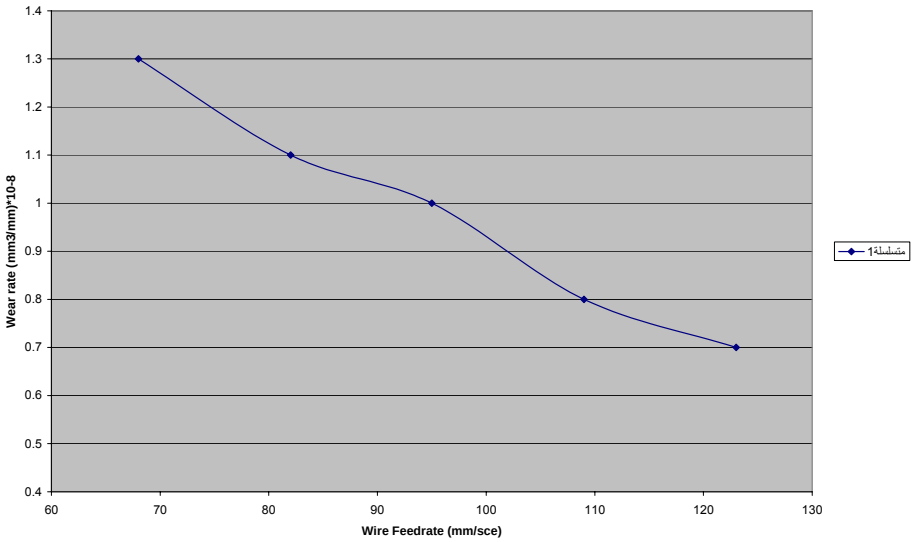


Fig (7) The relationship between the wires feed rate and wear rate

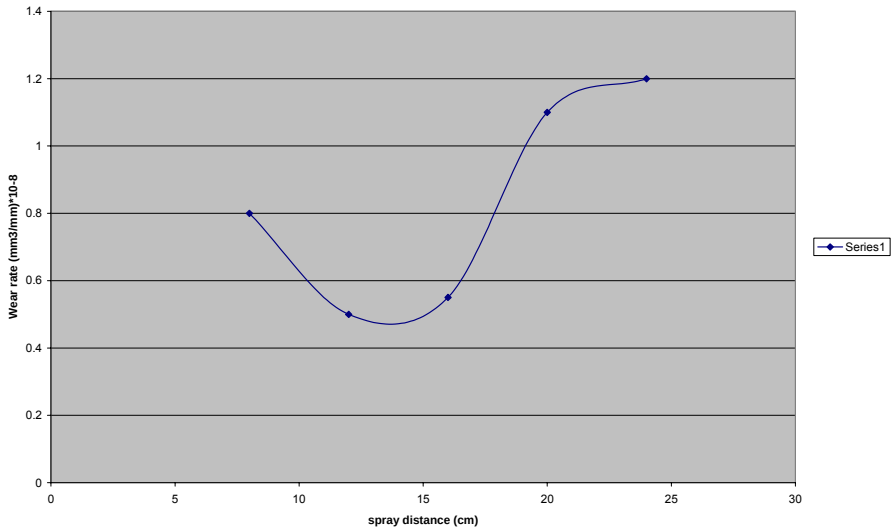


Fig (8) The relationship between the spraying distance and wear rate.

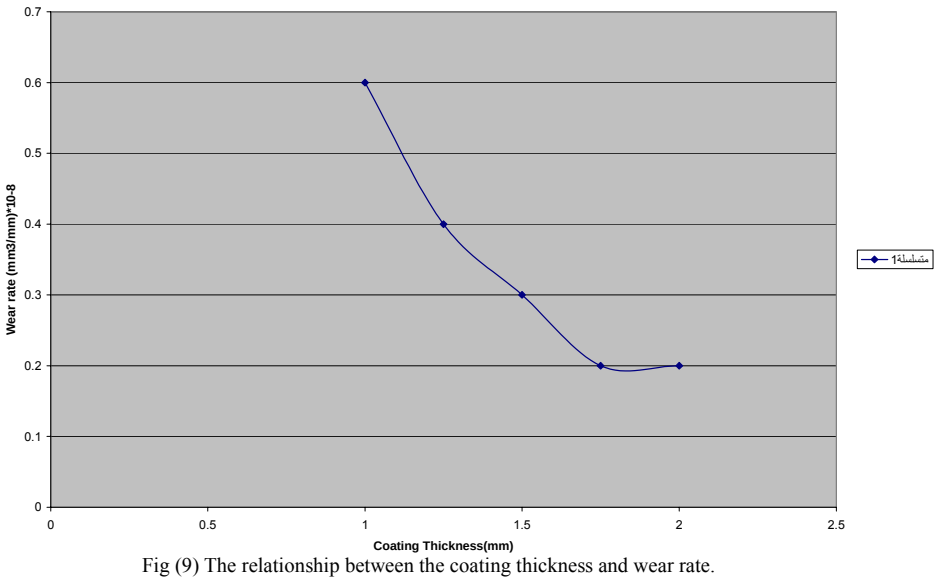


Fig (9) The relationship between the coating thickness and wear rate.



Fig (10): A typical microstructure of a sprayed coating showing the lamellar structure, oxides and porosity, (100X) unetched.

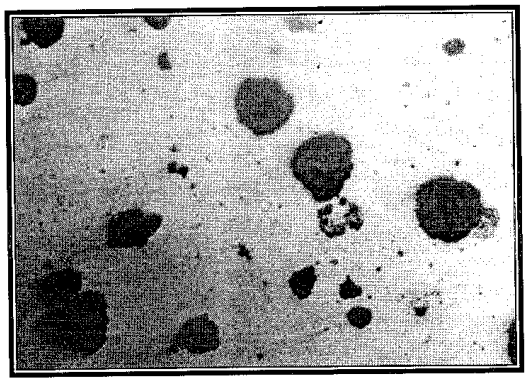


Fig (11): Optical microscopy picture, (200X), shows the microstructure of the base material, unetched.

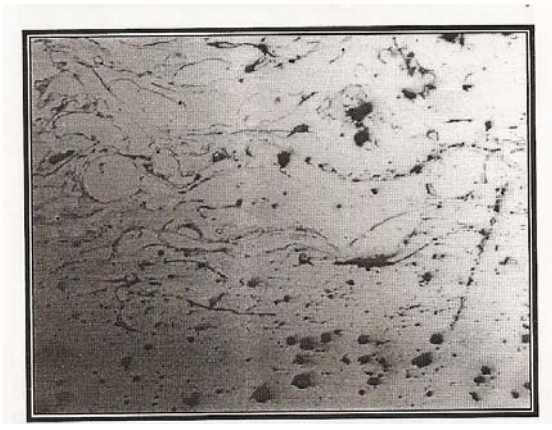


Fig. (12): Optical microscopy picture, (100X), shows the microstructure of the base with the coating layer, unetched.