# Optimizing the Process of Arc-Spraying To Improve Wear Resistance of Crank Shaft

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**Abstract**

This research studies the factors effecting on coating produced by electrical arc-spraying. The studied variables are applied voltage, wire feed rate and spraying distance.In this investigation used wires made from martinsitic stainless steel to coat the bearing of spherical graphite cast iron. range. The mechanical properties of coating such as hardness are used.Limited optimal environments by electric arc spraying to improve wear rate resistance of crank shaft.In the first stage all samples and metallizing wires were prepared and chemically analyzed. The coating operation was carried in the second stage. Each group of samples was coated in different way with variable spraying factor being considered. In the third stage all samples were tested using pin on ring wear testing machine. The investigation performed in this work showed that the process variable have a considerable effect on coating quality ,and spraying distance range emerges as the most significant process variables. The final results showed that the best voltage in this application is between 28-30V, wire feed rate is 100 mm/s, and best spraying distance is about 12-15cm to get a good coating with maximum wear resistance.

**Keywords:** Arc-spraying, Crankshaft repair, Wear resistance, Spray coating.

## الاختيار الافضل لمتغيرات عملية الرش بالقوس الكهربائي لتحسين مقاومة البلىللمحور القلاب

**الخلاصة**

اشتمل البحث على دراسة العوامل الموثرة على الاكساء المنفذ بطريقة الرش بالقوس الكهربائي.تم استخدام اسلاك من الفولاذ المقاوم للصدأ النوع المارتزايتي في اكساء مساند من نوع حديد الزهر ذي الكرافيت الكروي (الصب العقدي) . المتغيرات المدروسةهي الفولتيه المسلطة,معدل تغذية الاسلاك ومسافة الرش.تم تحديد الظروف المثلى للرش بالقوس الكهربائي لتحسين مقاومة بليان المحور القلاب.

نفذ البحث بثلاث مراحل متسلسلة.تضمنت المرحلة الاولى تحضير المعدن الاساس واسلاك الرش وتحليل مكوناتها الكيمياوية.في المرحلة الثانية تم تنفيذ عملية الاكساء .كل مجموعة من النماذج تم اكسائها بطريقة مختلفة حسب المتغيرات التي تم دراستها.في المرحلة الثالثة تم فحص النماذج باستخدام جهاز فحص البلى نوع (المسمار على الحلقة).

ان الاستقصاء المنجز في هذا العمل اظهر ان لمتغيرات العملية تاثير ملحوظ على جودة الطلاء وان مسافة الرش هي المتغير الاكثر تاثيرا من بين المتغيرات.

اظهرت النتائج االنهائية بان افضل فولتية لهذا التطبيق تتراح بين (28-30) فولت.وان افضل معدل لتغذية الاسلاك هو 100ملم/ثا.كما وجد ان افضل مسافة للرش تكون بحدود(12-15)سم للحصول على سطوح اكساء جيدة مع اعلى مقاومة البلى.

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## 1. Introduction

The wear phenomenon has a deleterious effect on all machines and mechanical equipment, which have sliding, rolling or reciprocating motion. As a result of these motions, all dimensions and measurements of the parts will be changed causing their replacement by new part. A save in cost can be obtained in the process of repair of worn parts by coating and put it back in service. [1]

The application of coating to surfaces which subjected to wear is usually considered when difficulties arise in the fabrication of complete component from the coating material or where the cost of the operation prohibitive. It my also be appropriative to use coating where different properties (electrical, mechanical or tribological) are required for the surface of the component compared with those in the core[1].

Higher accuracy and longer life are required for various machines as a result of advances in industrial technology consequently, control of the wear which occurs between sliding surfaces has become an important target [2].

Today surface engineering is essential in the application of high performance engineering materials. This is especially true due to both escalating costs of high performance structural materials and the increasing high life-cycle requirement of high performance systems.

Among thermal spraying techniques arc spraying offer low operating costs, high coating quality,

High deposition rates and efficiencies[3,4].

The material to be deposited serves as an arc electrode and thereby must have a very good electrical conductivity to make an arc ignition possible[5].

The material that is used to form the coating can be a powder, rod, wire or

Liquid. The material that is feed into the thermal spray process is termed feed stock, with the most common form being powder and wire.

The feed stock morphologies are selecting according to process. Arc metallization and the wire flame processes require wire as the feed stock, whereas the most common types of the gas flame and plasma processes require powders [6].

Preparation of substrates for thermal spray coating involves the spraying of abrasive particles against the substrate to remove contaminants and to condition the surfaces for subsequent spraying operations. Maximum bond strength is the most important coating attribute relative to thermal spray coating[7].

It is the process by which the pore of a coating are filled to eliminate the possibility of infiltration by fluid or corrosive media that can contribute to premature failure. In thermal spray coating, the porosity may range as 17-vol% and usually interconnected[8].

## 2. Experimental Work

### 2.1. Preparation

Crankshaft of nodular cast iron is used as substrate material. It's chemically analyzed by using mass spectroscopy instrument as shown in table (1).

Preparation of surfaces for coating is down as follows.

1. The crankshaft is heated, with soaking in a chemical solvent, to temperature of $300^0$C, these drives out the oil and foreign mater from oil hole.
2. Grinding to grades, using grinding wheels type (60 KSBE).
3. Painting the webs to prevent the unwanted sprayed metal adhering.
4. Ground the surface using silicon carbide papers to P1000.
5. Plugging oil with carbon sticks.
6. Coating surfaces by Ni-Al bond coat to a thickness approximately (0.05to0.1) mm, using the following operating parameters.Arc voltage =28V

Distance =8 cm
Wire feed rate =95mm/s

Now the surface is completely prepared for coating by 13%Cr steel. Since the important factor for the successful bonding of sprayed metal is the time lag between
Preparations and spraying, this must be kept to minimum. [8]

### 2.2. Coatiing With 13% Cr-Steel

The spraying operations have been carried out using an arc-spraying system (smart arc 350 PPG, sulzermetco, wehlen, switzerlad).

The wire to be sprayed with diameter of 1.6mm and its chemical composition is shown in table (1).

The coating process is done by changing applied voltage, wire feed rate and spraying distance range. Compressed air has been used as atomizing gas. The gas pressure of 6 bars is selected from prior experiments, in which the arc fluctuations were already optimized.

According to these variations, the specimens were numerated and divided in to three groups us shown in table (2).

### 2.3. Coating of The First Group

The first groups include 5 as shown in table (2), the coatings of which are done as the following sequence.

1. Completing all the work of preparation as in article (6.1)
2. Mounting the crankshaft on lath machine in front of gun with 90 angle of spray.
3. Rotate the crankshaft with speed of 30 r.p.m
4. Applying coating to a thickness equal to about 2.5 mm.
5. Each was coated with different applied voltage and keeps the other parameters constant as shown in table (3).
6. After complete coating for the first group the shaft is leave to cool.
7. Phenolic sealers are used after spraying and before surface finishing
8. Finishing to the required size by using wet grinding with medium hardness wheel type (vitrified 40-60 grit PEI).the surface speed is 180m/min and

work speed is 24 m/min insoluble oil is used as a coolant.

9. The coated is cutting from the repaired crankshaft and machine to the required size suitable for wear test machine as shown in fig.(1).

**2.4. Coating Of The Second Groups**

The second group includes also 5 journals. The same coating procedure is followed as in (6.2.1) except that the feed rate was used with variable values; the other variables were kept constant as shown in Table (4).

**2.5. Coating Of The Third Groups**

When all sequences of article (6.1) were completed coating of the third group were achieved with variation of the distance and keeping the other parameters constant as shown in Table(5).

**3. X- Ray Diffraction Test**

To describe the exact phases of coating material before and after the deposition, X-ray diffraction system type (Phillips 1050) was used. The elemental analysis technique employed was carried out under the following condition.

1. Scan speed =2 $^{o}$ /min
2. Chart speed =2cm/min
3. Applied voltage=40 KV
4. Current =20 A.
5. Wave length= 1.937 A $^{o}$ .

**4. Metallografic Examination**

The optical microscope type (leitz-metallu x3) was used to study the microstructure of coating; this microscope is delivered with camera to photograph the specimens.

**4.1. Hardness Testing**

Vickers hardness type (Wilson mechanical instrument division). The load used is 50Kg. [10].

**5. Wear Test**

Pin-on-Ring wear testing machine has been used during this work according to standard, which consist of an electric motor with variable speed from (0-1000) r.p.m. the tested journal is fixed horizontally on the rotating shaft tightly by screw, while the pin is fixed vertically on the by a vertical arm and pin holder as shown in fig(2).

The weighting method is the simplest way of detecting wear rate .the specimen after cleaning is weighed before and after running and the weight loss during the experiment is used to calculate the wear rate. The following relation is used to investigate the wear rate [11].

$K = \frac{Vr}{X}$, $Vr = \frac{\Delta m}{r}$, and

$X = Vs * T$

$$\therefore K = \frac{\Delta m}{r * Vs * T} = \frac{m_1 - m_2}{r * Vs * T} (mm^3/mm) \quad \text{---- (3)}$$

Where K=wear rate ($mm^3$/mm), Vr=weight loss (g), X=sliding distance (m), Vs=sliding speed (m/s), T= sliding time(S), $r$ =bulk density of coating ($g/mm^3$).

**6. Results And Discussion**

To understand more easily why the physical and mechanical properties of thermal sprayed coatings differ from a cast or wrought material of similar composition, it is necessary to discuss the metallographic structure of sprayed deposits.

A sample suitably prepared for metallographic examination reveals a heterogeneous mixture of sprayed material, oxide inclusion and pores as shown in Fig.(3).

Fig. (4) Show the microstructure of the base material (crankshaft).Spheroid graphite weakness the metallic matrix to lesser extent than flaky graphite. Nodular cast iron possessing high strength and high ductility which is much above that of gray cast iron. These high technological properties make it successfully used in manufacturing such important part as crankshaft for locomotive engine.

Fig. (5) Shows the X-Ray diffraction results for coating wire (13%Cr-steel) before spraying process. It show the presence of single iron phase type ($\alpha$ ).After coating process other phase is produced such as the presence of iron oxide ($Fe_2O_3$). The appearance of the oxide indicates the presence of iron oxide, which **nurture on** the particles during its flight from the gun to the substrate and after the deposition. [11]

### 6.1. Effect of applied voltage on wear

Wear is a surface phenomenon that occurs by displacement and detachment of material. 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 range of (28-30) V, beyond which there is an increase in wear rate. This range is corresponding to the maximum hardness shown in fig. (7).

Since the surface hardness is often consider as an important property indicating resistance to wear [12], the behavior of wear is appeared to be the inverse of the behavior of hardness.

### 6.2. Effect of wire feed

Fig. (8) Show 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.(9),i.e. minimum wear rate occurs at maximum hardness.

### 6.3. Effect of spray distance

The relationship between wear rate and spray distance is shown in fig.(10) .it is obvious from the figure that the wear rate decrease with increasing of spray distance up to12 cm, then it begins to increase with increase in spray distance.

The first behavior of the wear rate, i.e., decreasing stage up to 12 cm, can be attributed to the increase in hardness, as shown in fig. (11), 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 thin layer of oxide. This oxide layer hinders particles interaction and thus results in the formation of inter particle pores and provides a path for crack propagation in the particle intermediate layer[13]. 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 began to increase when the spray distance is beyond about 15 cm as shown in Fig. (10).

## 7. Conclusions

Arc spraying is a method of surface coating, which used mainly in the fabrication of repair and anti-wear coating. The quality of the spray deposit is greatly affected by spray parameters so the choice of these parameters should be based on the manufacturer recommendations, otherwise it must be found experimentally. From this work the following main conclusion can be made:

1. The arc voltage has some effect on both hardness and wear rate of coating. The best voltage range is between (28-30) V.
2- The best wire feed rate in this application is 100 mm/s.
3- Spray distance is the most significant process variable. there is an increase in coating hardness with increasing distance within the range of (8-24)cm. the best distance for maximum wear resistance is about (12-15)cm.

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**Table (1) chemical composition of used materials.**

| Element / Sample | %C | %Si | %Mn | %P | %S | %Cr | %Mo | %Ni | %Cu | %V | % Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Crankshaft** | 3.9 | 2.08 | 1.13 | 0.035 | 0.32 | 0.21 | 0.36 | 0.105 | 0.198 | 0.006 | Rem |
| **Coating Wire** | 0.326 | 0.388 | 0.717 | 0.038 | 0.017 | 13 | 0.048 | 0.288 | 0.065 | 0.068 | Rem |
| **pin** | 0.072 | 0.002 | 0.38 | 0.003 | 0.017 | - | 0.008 | - | - | 0.002 | Rem |
| **Bond wire** | Mn | Cu | Zn | Cr | Fe | Co | Mg | Al | Ni | - | - |
| | 2.265 | 0.042 | 0.114 | 0.073 | 13.74 | 0.26 | 1.079 | 5 | Rem | - | - |

**Table (2) the group of specimens to be coated**

| No | Group No | Journal No. in the grou1p | Variable |
|---|---|---|---|
| 1 | 1st group | 1v,2v,3v,4v,5v | Voltage(V) |
| 2 | 2nd group | 1f,2f,3f,4f,5f | Feed rate(m/s) |
| 3 | 3td group | 1d,2d,3d,4d,5d | Distance (mm) |

**Table (3) coating parameters of first group**

| Journal No. | Coating thickness after finishing (mm) | Applied voltage(V) | Distance(cm ) | Feed rate(mm/s) |
|---|---|---|---|---|
| 1v | 2 | 26 | 13 | 68 |
| 2v | 2 | 28 | 13 | 68 |
| 3v | 2 | 30 | 13 | 68 |
| 4v | 2 | 32 | 13 | 68 |
| 5v | 2 | 34 | 13 | 68 |

**Table (4) coating parameters of the second group**

| Journal No. | Coating thickness after finishing(mm) | Applied voltage(V) | Distance(cm) | Feed rate(mm/s) |
|---|---|---|---|---|
| 1f | 2 | 28 | 13 | 70 |
| 2f | 2 | 28 | 13 | 80 |
| 3f | 2 | 28 | 13 | 90 |
| 4f | 2 | 28 | 13 | 100 |
| 5f | 2 | 28 | 13 | 110 |

**Table (5) Coating parameter of third group**

| Journal No. | Coating thickness after finishing(mm) | Applied voltage(V) | Feed rate(mm/s) | Distance(cm) |
|---|---|---|---|---|
| 1d | 2 | 28 | 100 | 8 |
| 2d | 2 | 28 | 100 | 12 |
| 3d | 2 | 28 | 100 | 16 |
| 4d | 2 | 28 | 100 | 20 |
| 5d | 2 | 28 | 100 | 24 |

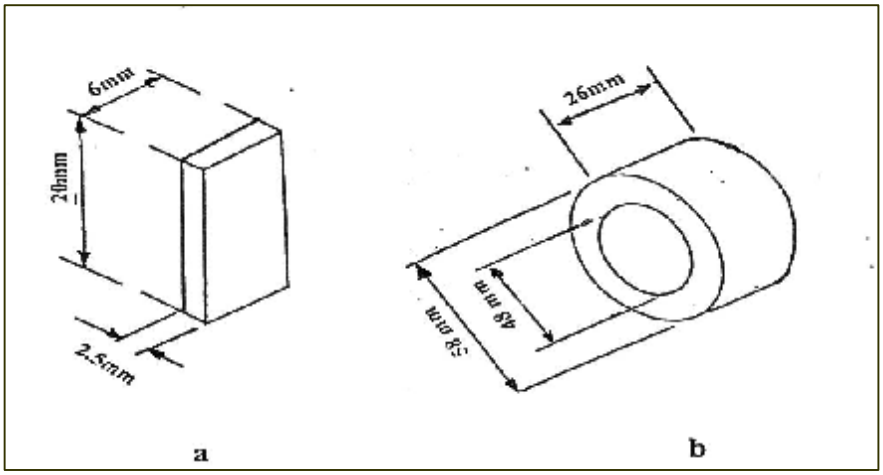


**Figure (1): a. Test Pin b. Test Journal.**

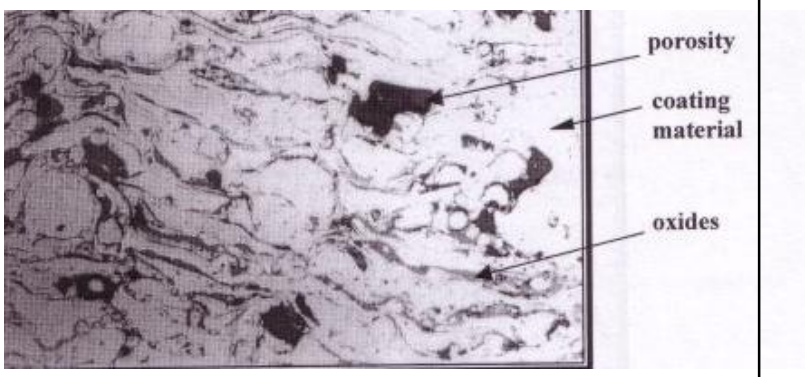


**Figure (2): A Typical microstructure of a sprayed coating showing the lamellar structure, oxides and porosity, (100X).**

**Figure (3): Optical microscopy picture shows the microstructure of the base material, (200X).**

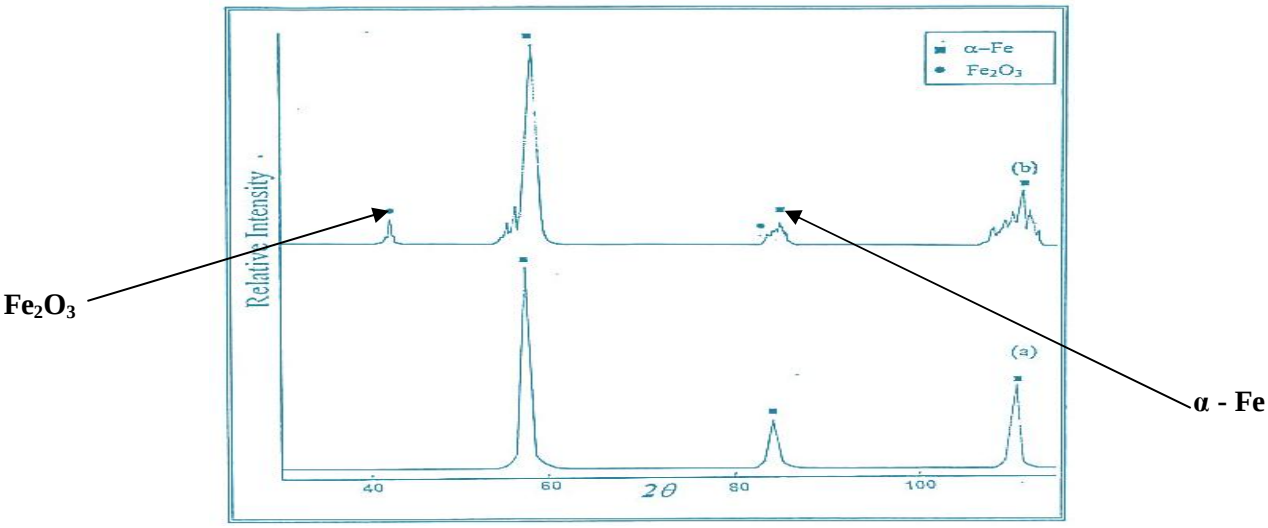


**Figure (4): X-ray diffraction results**
**a. Coating material before deposition.**
**b. Coating material after deposition.**

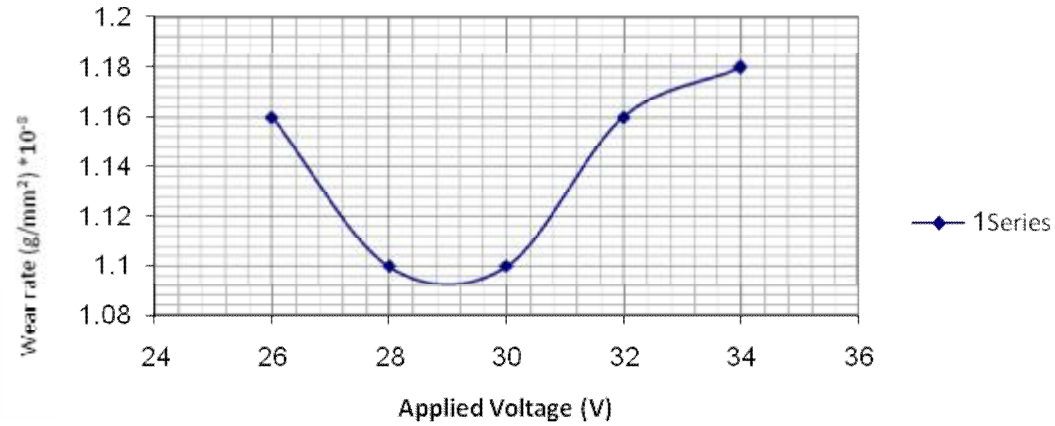


**Figure (5) The relationship between the appliedvoltage and wear rate**


**Figure (6) the .relationship between the applied voltage and hardness**

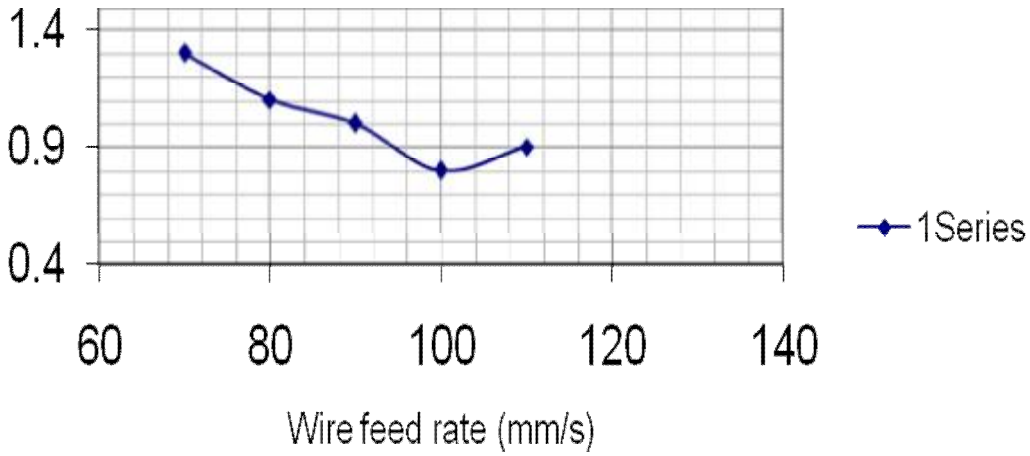


**Figure (7) The relationship between the Wire feed rate and wear rate**

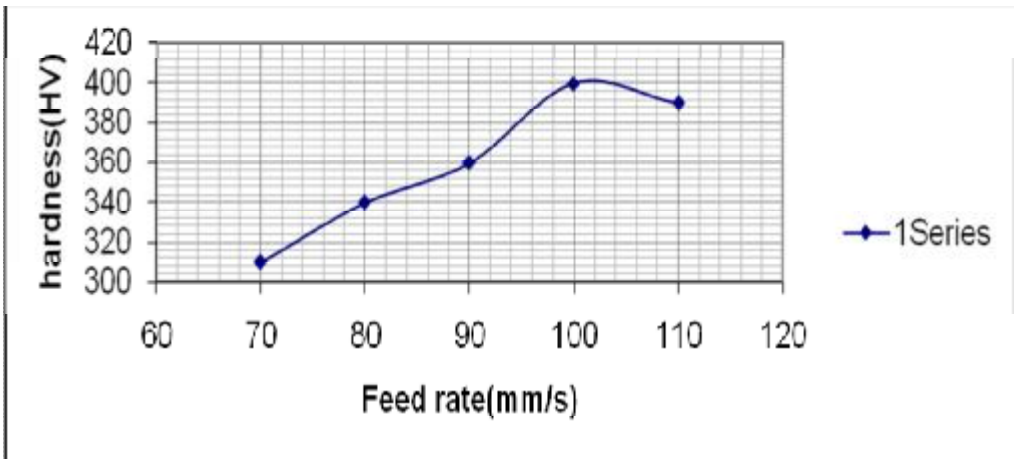


**Figure (8) The .relationship between the wire feed rate and hardness**

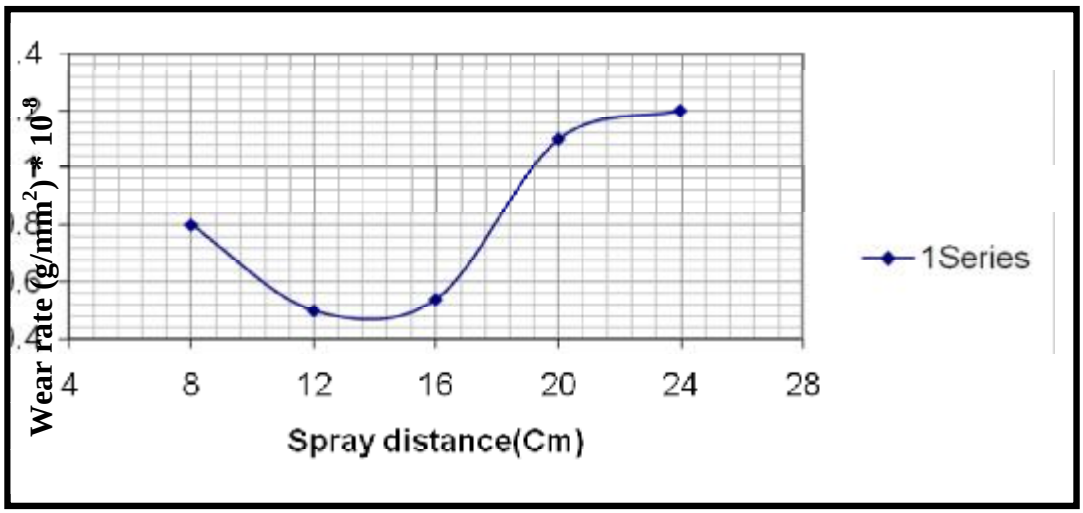


**Figure (9) The relationship between the spray distance and wear rate**

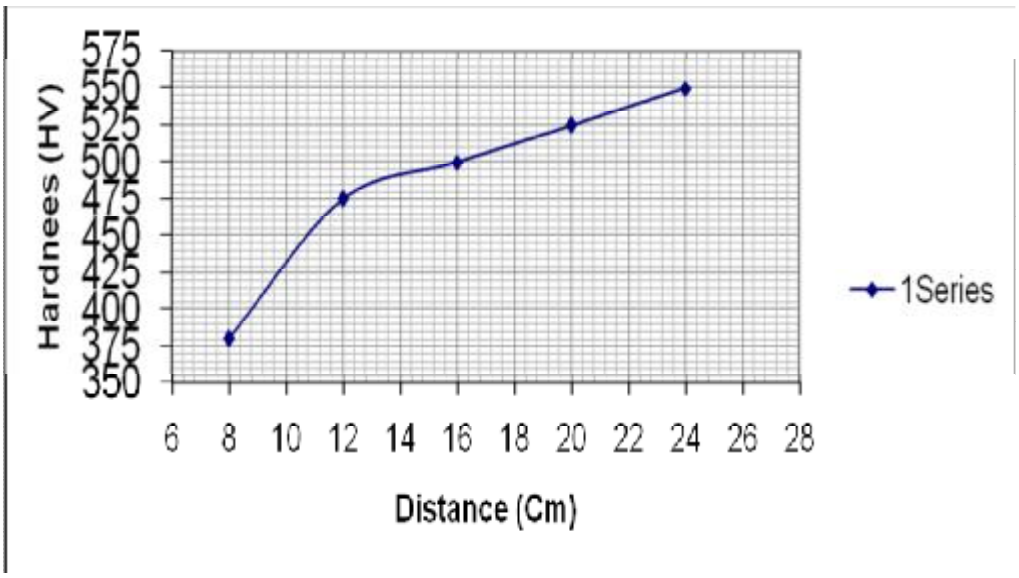


**Figure (10) the relationship between the spray distance and hardness**