PT-2 415

MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

EFFECT OF COLD METAL SPRAYING PARAMETERS ON SPRAYED LAYERS ADHESION STRENGTHS

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ABSTRACT

Cold spraying technique is applied employing austenitic alloy steel in coarse particles powder form sprayed by an oxy-acetylene spraying gun. The technique is carried out without preheating the sprayed surface. Fine bonding powder are employed to make adhesive substrate before spraying the basic powder which are sprayed in successive passes till reaching the required deposit thickness.

Special disc specimens of st 42 are sprayed at different spraying parameters (normal least distance between the spraying nozzle and the sprayed surface, the rotating speed of the specimens, the transverse speed of the spraying gun and the deposit thicknesses). The adhesion strength of specimens are examined via special hard steel die placed on the tensile-compression testing machine of 125 KN capacity. That is done by shearing the deposited sprayed layer off the parent material.

The adhesion strength of deposits mainly depend on the mechanical meshing among sprayed particles. Weak adhered sprayed deposits technique are not proper to carry shocks, concentrated loads and dynamic load except for bearing journals which are placed on soft bushes having the damping effect for shocks. Microstructure (metallography) examination has proved the above phenomenon. Recommended spraying parameters are advised to give deposits with reasonable adhesion strengths sustaining the adequate bearing loads.

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1. INTRODUCTION

Wear is one of the most important factors that affect the service life of the machine elements. One of the important objectives of maintenance is to minimize repair costs. Worn elements e.g. journals, gears, cams, turbine blades, extrusion dies and mating sliding surfaces have to be resized to the proper dimensions ensuring proper operating quality.

Needless to say that resizing techniques in most cases are cheaper and easier to employ in practice than the complete overhaul of worn parts. Different techniques of sub-merged arc welding, electric arc wire spraying, oxy-acetylene powder spraying (cold spraying at room temperature and hot spraying) and plasma spraying are oftenly used in resizing worn parts. The main features of the metal spraying processes were discussed elsewhere [1]. Most spraying processes are performed while the basic metal is at room temperature [2,3]. Therefore, little thermal stresses with low level of residual stresses are expected to result in the deposits layers. However, such a pre-heating status is recommended by Zaitsev [4]. The properties of the sprayed deposits will be determined mainly by chosing a suitable coating material, the spraying process, and in most cases, the spraying parameters [5]. As pre-sprayed layer, self-bonded powdered materials are selected so as to be instantaneously fused and self adhered to the substrates [6].

The most prevailing technique employed in resizing worn journals is the cold spraying technique. Such process needs no preheating of the surface to be sprayed. Anti-corrosive and or anti-wear layers, depending upon the employed spraying powder, may be attained by cold spraying ensuring longer working service, [2].

Our work is an original work. Its scope is to assess the optimum parameters of cold spraying which may affect the physical and mechanical properties of the achieved layers in particular those affecting their adherence capacity.

2. EXPERIMENTAL DETAILS:

2.1. Spraying technique setting up:

2.1.1. Employed powders for spraying:

There are two types of powders, the first type is the bonding powder which is employed to facilitate the adhesion of the second basic powder which gives anti-corrosive and/or anti-wear layer. The employed basic powder which gives both characteristics was analyzed in the National Centre of Researches. The following result was obtained;

Elements	:	C	Si	Mn	Cr	Ni	Fe
Percentage %	:	0.04	0.75	0.95	18.4	8.4	Rest
Morphology	:	Coarse spheriodal particles.					

The bonding powder is denoted "Xuper Bond 51000." The morphology of this type as revealed by National Centre of Researches was found to be fine spherical particles. However, its chemical composition, which is confidential to its makers, was found difficult to be obtained.

2.1.2. Spraying process:

Deposits are sprayed employing oxy-acetylene neutral flame (4 bar oxygen and 0.7 bar acetylene). The disc specimens are sprayed on an engine lathe by means of special chromium steel mandrel employing the following steps:

1. A bonding powder utilized as a substrate layer of 0.1-0.2 mm is to be sprayed utilizing the shown gun, Fig. 1, in order to ensure stable substrate.

2. The basic powder is to be sprayed utilizing the same gun to obtain the required deposit thickness after spraying successive passes.

2.2. Shear Tests setting up:

2.2.1. Test rig:

The adhesion strengths of the sprayed layers are measured via a special testing die designed to shear the deposited layer off the basic metal. Needed shear tests are carried out utilizing a 125 KN tensile-compression testing machine, at a steady loading velocity of 0.5 mm/min. Compression loads are applied via die upper part (1) [Fig.(2)] which acts upon the basic metal of the specimen (2). The latter part (2) is settled above the die lower part (3).

The shearing die is made of hard chromium steel (SPECIAL KR SIS 2312) with the following chemical composition;

Elements :	C	Cr	V	W	Fe
Percentage %:	2.1	11.5	0.2	0.7	balance

The die lower portion is quenched and then tempered to a hardness of 65 RC in order to attain a high level of wear resistance especially at its cutting edge. Care is taken to maintain same die edge sharpness in order to get repeatable results.

2.2.2. Test specimens:

Disc specimens are chosen of St42 DIN 110. The mechanical properties are measured by the "Laboratory of Suez Canal Authority for Researches" and found to be as follows:

Ultimate tensile strength	= 452 N/mm^2
Yielding stress	= 280 N/mm^2
Elongation percentage %	= 26,8

Hardness = 182 HV.
Toughness = 1,962 N m/mm^2

Shear test specimen preparation steps are performed as follows:

1. A preliminary test specimen (to be later discarded), of 35 mm diameter is to be threaded with special fine thread of 120° included angle, 0.5mm pitch, 0.3mm depth and then sprayed by same bonding powder.

2. The resulted bonding material substrate thickness (T_b) ranges between 0.1-0.2 mm, is to be obtained.

3. Test specimen is to be machined to a diameter of [35-($2T_b$+0.1)] mm taking into consideration the preliminary steps which have to be prepared before spraying specimens (Appendix I).

4. The bonding powder is sprayed employing spraying conditions like those employed at spraying the discarded specimen.

5. The basic powder is sprayed up to the required deposit thickness.

6. Test specimen is to be finish machined by turning in order to arrive at the needed specimens test dimensions as shown in Fig. (3).

2.2.3 Test conditons:

Shear test groups are performed in order to indicate the effect of the change in the spraying parameters viz; the normal least distance (L) between the spraying gun nozzle and the specimen surface, the rotating speed (N) of the sprayed specimens, the transverse speed (F) of the spraying gun and the deposits thicknesses (T) on the sprayed deposits adhesion strengths (ζ), taking into consideration that, for every change, the other spraying parameters are held constant.

It should be noted that spraying gun transverse speeds (F) in mm/rev. are adjusted to keep the gun speed (F) in mm/min, more or less constant for the different rotating speeds (N).

3. EXPERIMENTAL OBSERVATIONS:

3.1. Spraying process observations:

Spraying at shorter least distances less than 100 mm with 240 r.p.m rotating speed and 960 mm/min. transverse speed, as well as, at lower transverse speeds less than 120 mm/min employed at 200 least distance, with same rotating speed, oftenly, result in deposits having thicknesses higher than 0.3 mm per pass. It is also associated with visible cracks which cause deposits failure during machining. Spraying deposits of accumulative layer thickness more than 1.25 mm at 200 mm least distance, 240 r.p.m.rotating speed and 960 mm/min transverse speed give the same above result. Such incorrect spraying parameters raise deposits temperature up to more than 300°C leading, hence, to overheating and thermal cracks. Spraying at least distances greater than 260 mm and or at higher rotating speeds greater than 800 r.p.m. result in weaker deposits which oftenly fail during the post machining. Lower rotating speeds less than 76 r.p.m. at 200 mm least distance and 960 mm/min. transverse speed give irregular deposits.

3.2. Shear tests observations:

Separation (shear) has occurred, always in the zone of the bonding layer. Oftenly, the sheared deposits are in the form of open rings. Threaded helix like that prepared before spraying deposits is found to prevail for both resulted surfaces, the inner surface of the sheared ring (deposit) and the test specimen surface of the bonding layer remainder. Such results indicate that the sprayed layers are mostly, brittle.

4. RESULTS AND DISCUSSION:

No metallurgical diffusion is evident between the sprayed deposits and the basic metal. Proper employment of sprayed bonding layer technique ensure adequate adhesive layer strength of the post sprayed deposit. Incomplete sintering is expected to prevail for deposited layers since their temperature is less than 300°C. The adhesion strengths among sprayed particles and those between deposited particles and the parent metal depend mainly on the mechanical meshing of the deformed particles. Such meshing is ensured by the proper striking momentum and plasticity of the deformed particles.

Fig. (4) gives a plot of the variation between the adhesion strength of the sprayed layer (ζ) and the distance (L). It is found that (ζ) increase for higher (L) up to 180 mm. If (L) is shorter and between 100 mm and 180 mm it will ensure adequate sprayed particles plasticity together with higher particles striking momentum. This in turn leads to dense sprayed deposits with low deposits permeability (Fig. 8). Although such cases seem to ensure adequate mechanical meshing, yet deposits get overheated (temperature rise range between 250-300°C). Such temperatures cause relative burning or excessive brittleness of the sprayed bonding layer (Fig. 8). This results in weaker adhesive substrate. Excessive deposits overheating with recorded temperature rise more than 300°C are found to prevail for deposits sprayed at (L) shorter than 100 mm. Such circumstances result in complete bonding layer burning associated with visible cracks at the two end faces of the substrate. This eventually lead to deposit separation during the post machining. That may be the reason why no positive results are encountered at distances equal or shorter than 100 mm. Decreases in (ζ) are also found to be evident associated with more voids resulting from higher porosity percentages for (L) more than 180 mm. Distance (L) increase over 180 mm up to 260 mm lead subsequently to greater cooling of the particles before striking associated with inferior striking ability together with low plasticity. Weaker adhesion strengths are associated, normally, with higher permeability of such deposited layers. Fig. (8) indicate also the effect of least distance (L) on the deposited layers overheating and porosity.

Fig. (5) gives representation of deposits adhesion strength (ζ) against specimen rotating speed (N). As specimen speed (N) increases, sprayed layer adhesion strength (ζ) gets weaker. As (N) gets smaller so do the aero-dynamic and centrifugal effects on particles impact momentum yielding layers of higher adhesion strength (Fig. 9). This argument is confirmed by the noticeable decrease of deposited layer permeability as (N) gets smaller and vice versa.

No effect of gun transverse speed (F) in the range of 120-1920 mm/min upon the sprayed layer adhesion strength (ζ) is, practically noted beyond experimental errors (Fig. 6).

Spraying deposits of total thicknesses (T) ranging between 0.25-0.5 mm give layers with reasonable values of adhesion strength (ζ) [refer to Fig. 7]. Noticeable decreases in adhesion strengths (ζ) are revealed for layers superior than 0.5 mm thick. This is due to deposits overheating (temperature rise is more than 250°C) caused by the successive spraying passes which in turn result in weaker adhered bonding layers (Fig. 9). Fig. MD6, indicate thicker deposited layer of 1.25 mm thick with low porosity percentage but it gets overheated resulting in weaker interface adhesion strength (ζ).

5. CONCLUSIONS:

1. The optimum adhesion strengths is found, here, to be at a least distance of about 180 mm.
2. Spraying powder particles striking momentum and deposited layers permeability at such distances are expected to be adequate.
3. Low rotating speed ranging between 8-10 m/min. ensure higher sprayed layer adhesion strengths for specimens having diameters of 35 mm.
4. Such rotating speeds, oftenly, are suitable to get low aerodynamic effect and low porosity rating.
5. A gun transverse speed range of 2-4 mm/rev. is recommended with rotational speeds of 8 to 10 m/min. for specimens of 35 mm diameter. The above feed range yields per pass deposits ranging between

0.1 to 0.2 mm. Feed values outside that range either necessitate many passes to get the required deposit thickness or lead to thicker per pass deposit giving higher sprayed deposit temperatures which result in weaker adhered

6. It is recommended to spray layers of thicknesses ranging between 0.25-0.5 mm in order to ensure fair values of adhesion strength for sprayed layers with reasonable deposits permeability.

6. CONCLUDING REMARKS:

It is revealed that cold spraying technique gives compensated layers adhered mechanically with lower ability to sustain shocks or concentrated loads. Moreover, it is proved that adhesion strength as well as the mechanical properties of the sprayed bonding layers are poor. In conclusion cold metal spraying layers are brittle and weak except for resized bearing journals which are placed on soft bushes having the damping effect for shocks.

7. REFERENCES

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2. D.H. James. "Thermal spraying by electric arc process", the metallurgist and materials technologist, February, 1983.

3. W. Wood and Lamb. "Powder in thermal spary applciation". Journal of British ceramic society, Vol. 1 No. 3, Dec. 1984 Page 402.

4. L. Zaitsev, "Porosity in weldment caused by wetted electrodes. Iron - Steel Institute 152, 127.

5. M.P. Overs, "Fretting wear and Fatigue of Molydenum sprayed coatings". M.Sc. Thesis, Nottigham Univ., 1978.

6. Metco Ltd. "Thermo - spraying", Technical report, USA, 1983.

8. APPENDIX 1:

Specimens preparation for spraying:

Needed preliminary steps are performed before spraying specimens as follows:

1. Turning specimens in order to remove oxide films.
2. Cleaning specimen's surface utilizing benzene in order to remove oils and/or grease if any.
3. Cleaning the employed cutting tool edges as above.

4. Making chamfer of 2 mm x 45° at the two sides of the surface prepared for spraying.
5. Making special fine thread of 120° angle, 0.5mm pitch, 0.3 mm depth in order to ensure adequate strength for the sprayed layer.
6. Cleaning the threaded surface with ethyl alcohol.
7. Passing hot air draft to dry the sprayed surface.

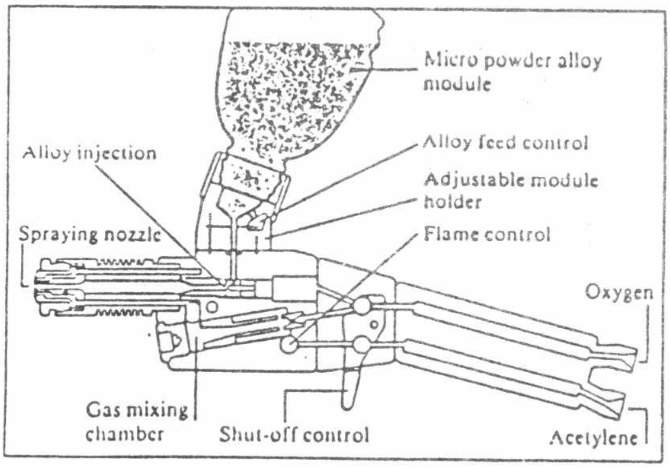


Fig.1 Spraying gun

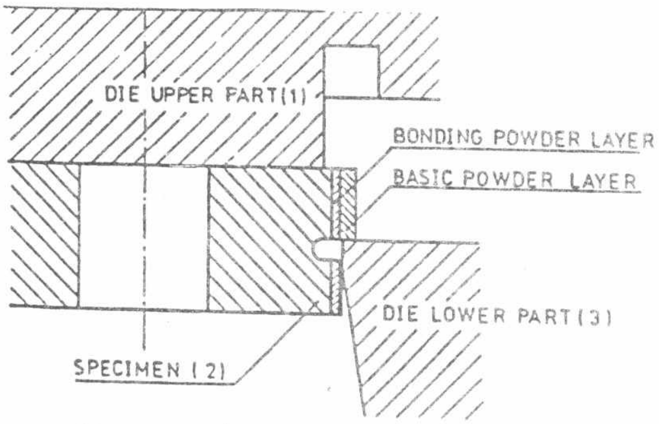


Fig.2 Representation of applied shearing mechanism

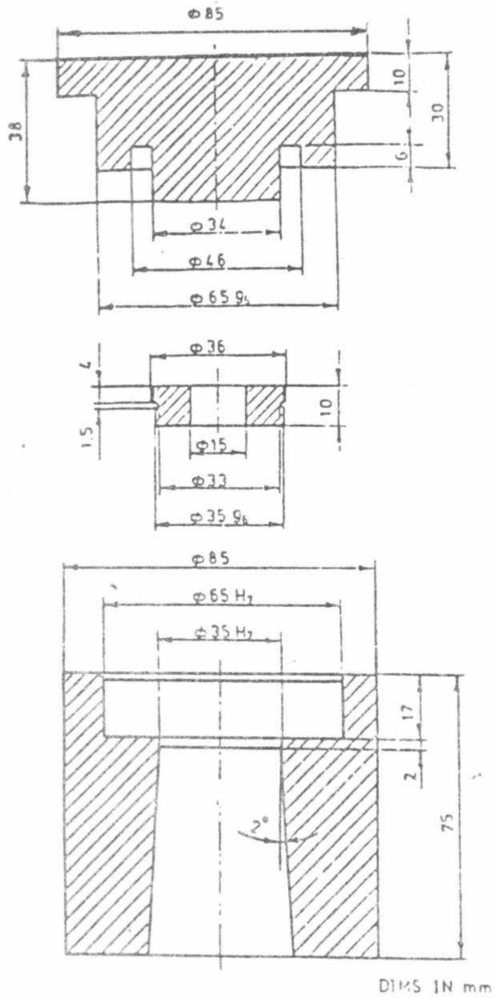


Fig.3 Particulars of shearing die

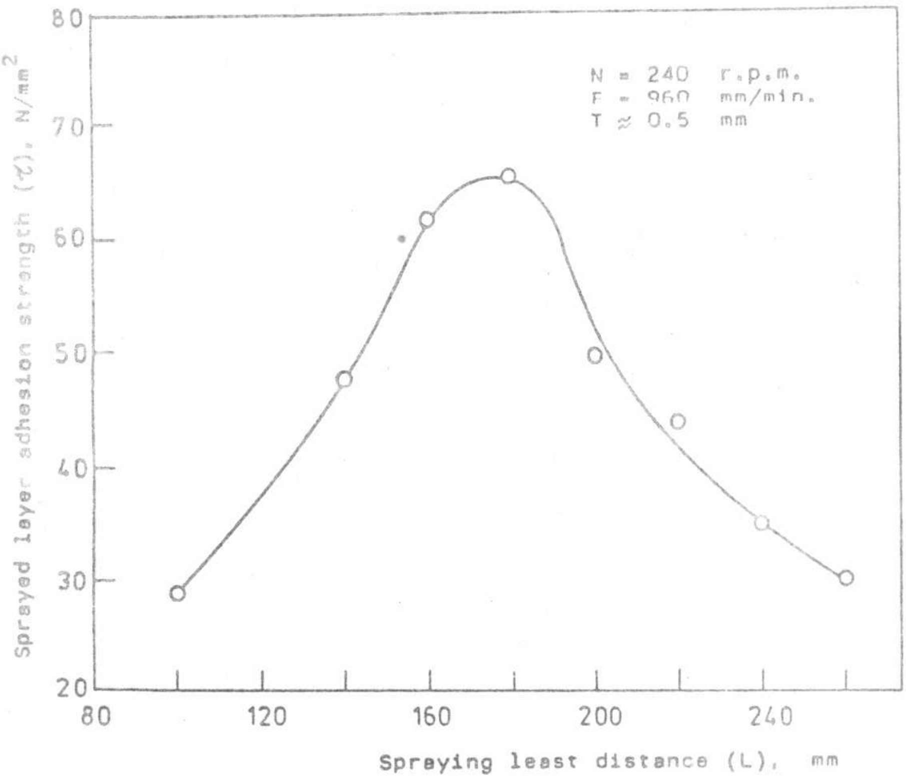


Fig.4 The effect of spraying least distance (L) on Sprayed layer adhesion strength (τ).

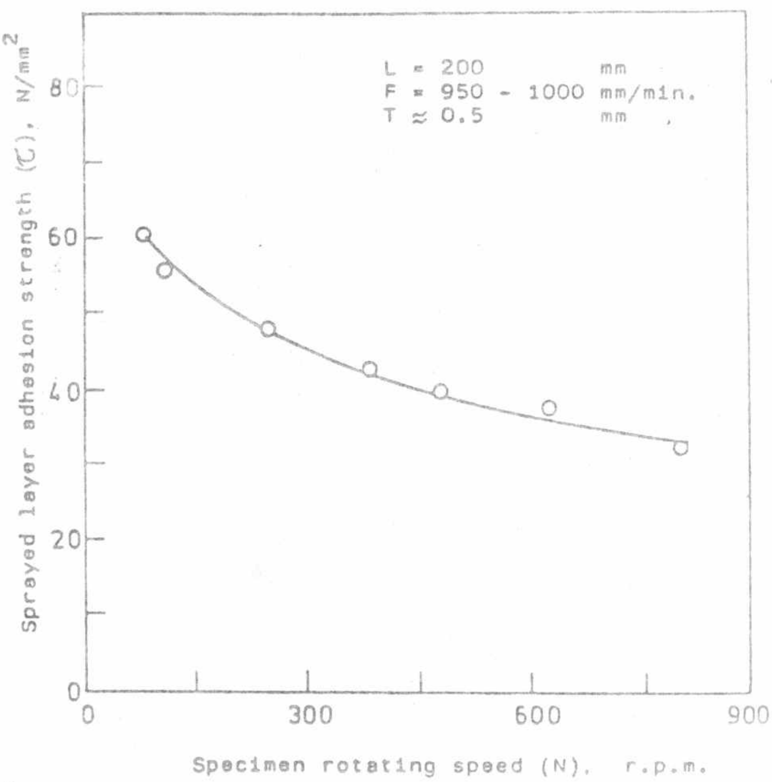


Fig.5 The effect of specimen rotating speed (N) on sprayed layer adhesion strength (τ).

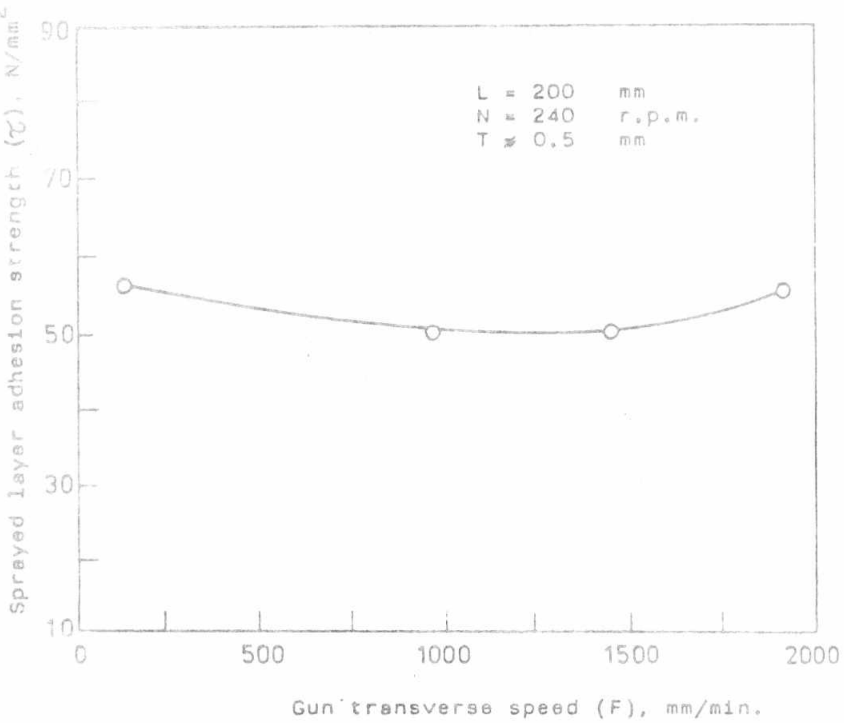


Fig.6 The effect of gun transverse speed (F) on sprayed layer adhesion strength (τ).

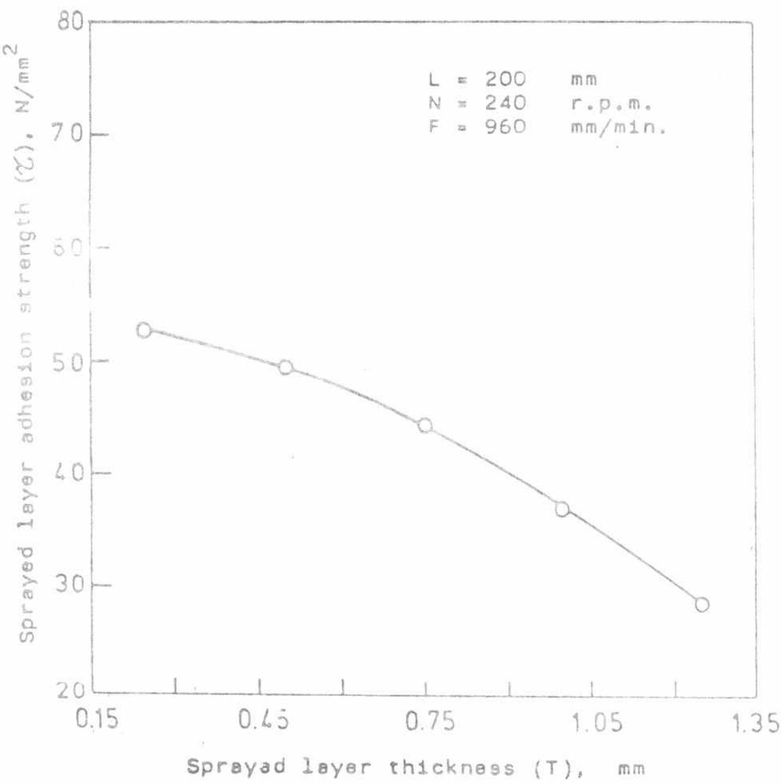
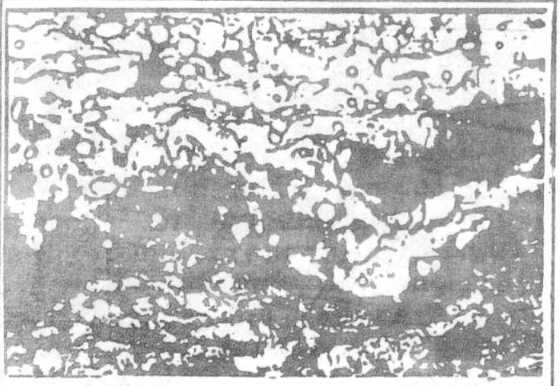
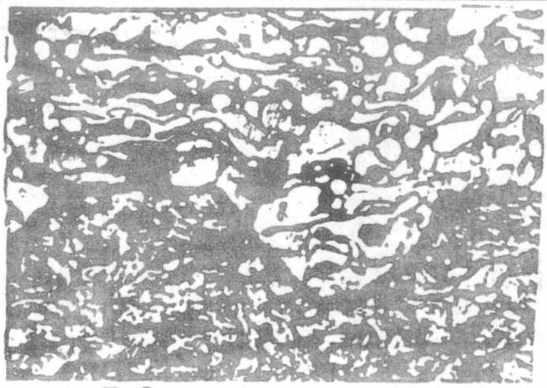


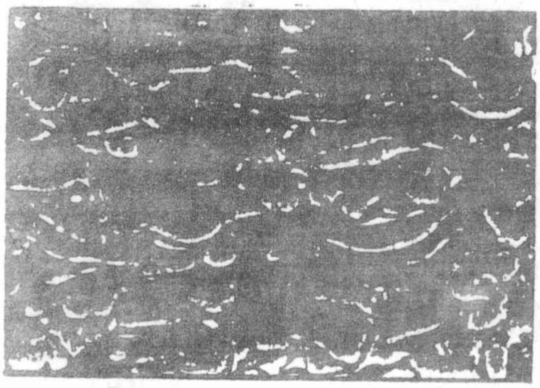
Fig.7 The effect of sprayed layer thickness (T) on sprayed layer adhesion strength (τ).



MI-1 X100



MI-2 X100

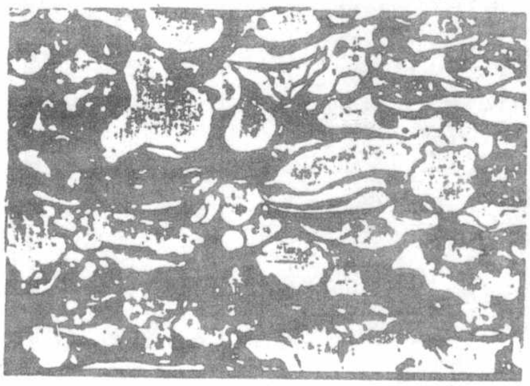


MD-1 X200

L=100 mm , N=240 r.p.m

F=960 mm/min , T≃ 0.5 mm

Test NO.1

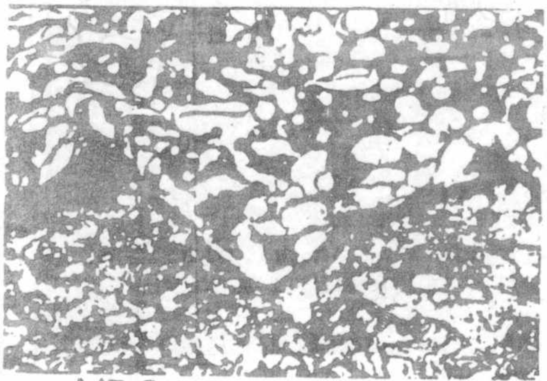


MD-2 X200

L=200 mm , N=240 r.p.m

F=960 mm/min , T ≃ 0.5 mm

Test NO. 2



MI-3 X100

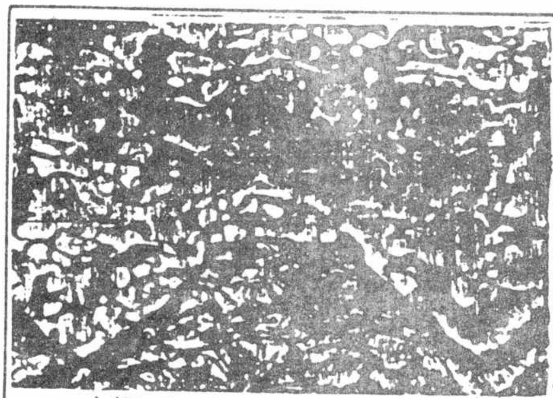
MD-3 X200

L=260 mm , N=240 r.p.m , F=960 mm / min , T≃ 0.5 mm

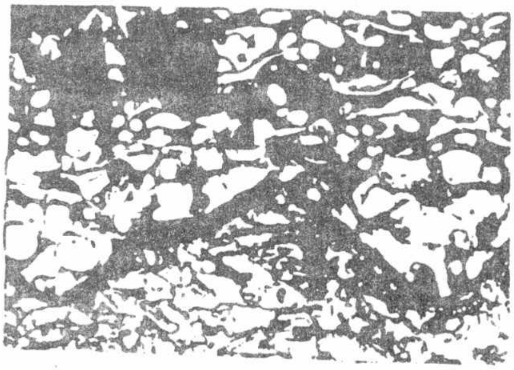
Test NO.3

(Fig. 8) Some micro-structure tests [NO. 1,2 and 3]

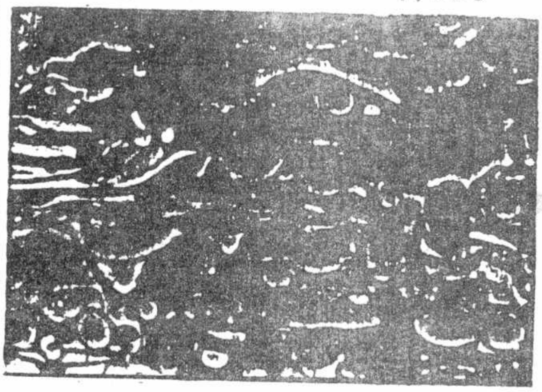
(MI – Interface , MD – Sprayed deposit)



MI-4 X100



MI-5 X100

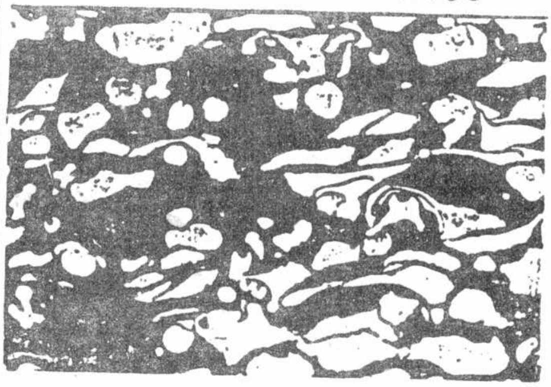


MD-4 X200

L=200 mm , N=76 r.p.m

F=950-1000 mm/min , T=0.5 mm

Test NO. 4

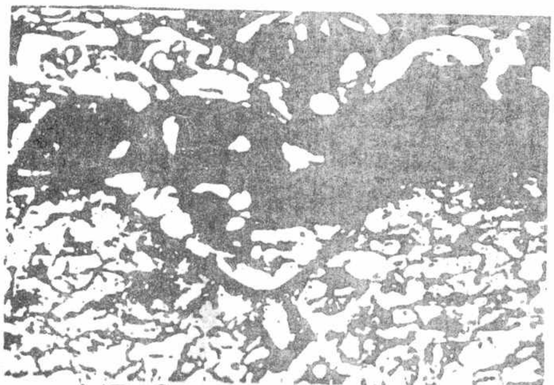


MD-5 X200

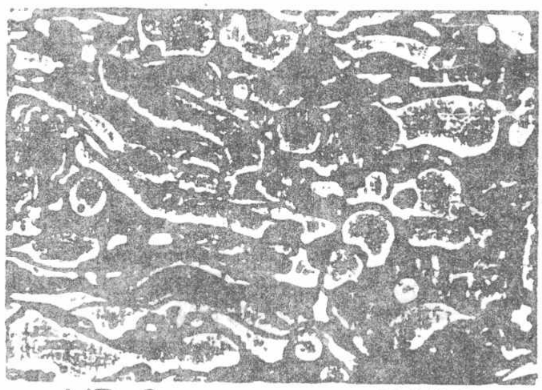
L=200 mm , N=800 r.p.m

F=950-1000 mm/min , T=0.5 mm

Test NO. 5



MI-6 X100



MD-6 X200

L=200 mm , N=240 r.p.m , F=960 mm/min , T=1.25 mm

Test NO.6

(Fig. 9) Further micro-structure tests [NO. 4,5 and 6]