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THE COLLEGE OF AERONAUTICS

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ASSESSMENT OF BLASTED SURFACES

Research Project 1 of the Metal Spraying and Coating Division
of the Institute of Welding

PROGRESS REPORT No. 1

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DEPARTMENT OF MATERIALS

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Introduction

The quality of a sprayed metal deposit is known to be related to the nature of the prepared surface of the base metal. Grit blasting is a common method of surface preparation, and the actual profile or surface contour of the prepared surface can be varied considerably by variation in blasting conditions. The exact requirements of an acceptable surface have never been accurately stated, although a degree of undercut is considered essential.

The object of the present work is to develop a non-destructive method for the assessment of blasted mild steel surfaces in terms of suitability for metal spraying. Such a method needs to combine simplicity and speed, so that it can be used by normal inspection personnel without delaying production. Preferably the method should incorporate a 'fail-safe' mechanism.

A number of possible assessment methods have been considered, but attention has been largely concentrated on measurement of the diffuse reflectivity of blasted surfaces. In reality, of course, this is simply an attempt to replace the eye in visual inspection with an instrument, and so remove the human element. Results have been reasonably encouraging, but it is obvious that many more samples need to be examined before a true judgement can be made.

Some difficulty has been encountered in deciding the requirements for an acceptable surface. For this reason, a part of the experimental effort has been devoted to the examination of blasted surfaces, and to the measurement of bond strength after metal spraying.

A brief review of literature has also been included.

Review of literature

Little specific information has been published on surface preparation for metal spraying, and none at all on the non-destructive assessment of prepared surfaces. However, a brief survey of literature on metal spraying in general does bring out a number of points of interest. This literature shows that metal spraying has been developed to the stage where it is an extremely useful fabrication tool. Rather more attention has been paid to articles covering surface preparation for spraying by blasting methods, which show that the practice of surface preparation has outstripped the theory. Assessment of blasted surfaces must ultimately be based on the bond strength between the sprayed coating and the base metal; for this reason, attention has been paid to methods of measuring bond quality. Unfortunately, these methods have largely been developed for cylindrical surfaces and little information is available for flat surfaces.

General literature on metal spraying

The development of metal spraying from an art to a technology is still in its early stages. The art and practice of metal spraying is well developed, giving consistent and reliable results, but the basic science of the process and the nature of the bond is less well understood. The literature on metal spraying reflects this position - a number of excellent books(1,2) and articles(3-9) on metal spraying practice exist, but published information on metal transfer, bond strength, etc., is sparse. However, these articles do give a general appreciation of the wide range of metal spraying applications and of the problems that face the production engineer.(10)

A further article(11) suggests fields for research in metal spraying. Special mention is made of surface preparation prior to spraying, development of equipment, characteristics and properties of the sprayed deposit (including bonding), and subsequent treatment of sprayed surfaces.

Surface preparation for metal spraying

Some of the general articles(1,2,3,12) list the method of surface preparation used prior to spraying. Briefly these include:

1) grit blasting
2) molybdenum spray bonding
3) rough threading (cylindrical bases only)
4) electric bonding
5) rotary roughening.

The present project is concerned with grit blasting, and details of grit blasting methods and processes have been covered by several authors.(10,13,14) Blasting may be carried out using

a) washed, salt-free, angular silica sand, crushed garnet, or fused silica.
b) round steel shot or cut steel wire
c) angular steel grit
d) angular chilled iron grit.

The use of silica can be expensive, particularly since rapid breakdown of the particles occurs, whilst the use of the cheaper sand can lead to silicosis if used in confined spaces. Round steel shot and cut steel wire is also unsuitable, since it produces a surface with insufficient undercut for 'keying' of the sprayed and base metals, whilst cleaning is also reported to be rather unreliable(10). Angular chilled iron or steel grit are generally agreed to be the best blasting media.

The condition of the grit is important(4); it needs to be free from fines or rounds, whilst the air supply must be free from oil. The air pressure is also important being governed by the thickness and material of the coating subsequently required. Thus while only 30 p.s.i. is necessary for a 0.005 inch layer of zinc, 40 p.s.i. is necessary for 0.010 inch aluminium and 80 p.s.i. for a thick coating of steel. The conditions that must be fulfilled by blasting are generally agreed[4,15] i.e.

a) all foreign matter such as paint, rust, and scale must be removed from the surface
b) adequate roughening and complete coverage of the surface is necessary
c) an undercut surface is necessary for good 'keying' of the sprayed and base metals, with resultant good bond strength.

Another writer[16] has described the ideal base for metal spraying as a fibrous matt surface, similar in appearance to coarse Harris tweed.

The requirements of a blasted surface prepared for metal spraying have been discussed far less. The need for undercut has been stated,[1,4] while another writer[10] considered that a suitable blasted surface needs 10,000 peaks per square inch. Assessment of blasted surfaces appears to be largely carried out by sight and feel of the surface, although general agreement exists that more reliable assessment techniques are necessary.[5,11] The difficulty of the problem is increased by the fact that little is known of the basic requirements of the blasted surface and one writer[4] has stated that grit blasting is not a method that leads readily to visual inspection.

Attempts have been made to place the visual inspection of surfaces prepared for subsequent treatment on a more secure basis by providing standards for comparison[17,18], but these still reply on human judgement. References[17,18] show pictorially a wide range of surfaces, satisfactory and unsatisfactory. These photographs are intended to be used directly by inspectors on the shop floor. The British Standard for metal spraying[19] requires a scratch test on a sprayed test coupon, on which two parallel scribe marks are made 1/8 inch apart; if the coating peels away the work is rejected. This test, however, is only qualitative and is not generally regarded as satisfactory since test coupons do not always reflect conditions on the workpiece. Other qualitative tests, involving chipping and peeling of coatings on test coupons, are also unsatisfactory for the same reason. Tests for bond strength, involving shear or tension, might be worthwhile, but also involve test coupons and, additionally, are time consuming.

Bond strength of sprayed surfaces

The nature of the bond between sprayed metal coatings and base metal is generally accepted to be largely due to mechanical 'keying'[20]. This would explain the importance of surface roughness and undercut, which has also been demonstrated for sprayed ceramic coatings[21]. A suggestion that pressure welding was also of importance[22] for bond strength is generally regarded as less likely. In the case of sprayed molybdenum, which will bond to comparatively smooth surfaces, a twofold mechanism has been suggested[23].

a) The formation of an alloy layer between the base and the deposit.
b) Infiltration of fused metal from the basal surface into the pores of the deposit.

Tests for bond strength involving both shear and tensile strength of the bond have been reported for cylindrical[9,21,24,25] and flat specimens[9,26,27].

For shear tests on cylindrical specimens, a cylinder of known size is sprayed with a specific thickness of metal, and a longitudinal cut is made through the coating to eliminate any bonding due to shrinkage. The cylinder is then forced through a die block containing a hole having the exact size of the cylinder prior to spraying, causing shear of the spray bond (Figure 1). For testing the tensile (or 'pull-off') strength of the bond, a plug with an easy sliding fit is fitted into a hole perpendicular to the axis of the cylinder, and the load to remove this plug after metal spraying is measured on a tensile machine (Figure 1b). Both tests are claimed to give reasonably consistent results, although they are time consuming.

Measurement of bond strength of flat specimens under tensile and shear conditions presents rather more difficulties, and no shear tests have been reported. The problem with tensile tests[9,26,27] is to avoid shear, which can lead to widely inconsistent results. In one test[27], the end face of a cylinder fitted with a sliding fit plug is sprayed and the force to remove the plug is measured - this test removes any shearing forces but the area of loading cannot be determined exactly.

In a further test[26], a circular groove is machined in the sprayed surface, leaving a free standing sprayed area. A steel rod is bonded to this area with an adhesive and the 'pull-off' load of the sprayed coating measured in a tensile machine (Figure 2). It is claimed that the machined groove eliminates shear effects, although, in fact, reproducibility of test results is not good, varying from 0.30 - 0.52 t.s.i. in one case.

Tests for surface films, oil and grease

Surface contamination by oil and grease can be a problem with material prepared for spraying. Oil and grease can be introduced to the surface by a contaminated compressed air or grit supply; its presence can produce markedly inferior bond strength between the sprayed coating and base metal. Since visual inspection of surfaces prepared for metal spraying is unlikely to detect the presence of surface oil or grease, a simple test method is necessary. Such a method should meet the requirements of simplicity of application and interpretation, and should leave the surface in a suitable condition for spraying without the need for any subsequent treatment.

No detection methods specifically designed for oil on blasted surfaces have been reported, but one writer[28] has covered methods for metal surfaces generally. Little problem exists with superfluous layers of oil which can often be detected visually. Dusting of the surface with, say, powdered chalk will show up oil, whilst in addition, most oils fluoresce in ultra violet light, which also offers a detection method.

Thin, absorbed layers of oil offer more difficulty. Such a layer will prevent a drop of water spreading and this test operates quite well on smooth surfaces. A selective staining method can also be used for both absorbed and superfluous layers of oil. In this method, the test surface is immersed in a solution of basic fuchsin in carbonic acid, glycerine, and water. The test surface is then removed and rinsed with clean water and if oil is present the surface will display a pink coloration. This method is reported to be very sensitive and could possibly be applied to blasted surfaces.

A further method for the detection of thin oil films involves placing a drop of solvent on the surface to be tested and allowing it to evaporate. If the surface is clean no trace of the drop will remain, but if oil is present a dark stain will be visible around the periphery of the drop. This method is reported to be satisfactory for blasted surfaces.[29]

Experimental work

Introduction

As mentioned above, the main requirements of any method for the assessment of grit blasted surfaces prior to metal spraying are simplicity and speed. Possible methods that might meet these requirements are

1) measurements of surface contour
2) measurement of the adhesion to the surface of an appropriate adhesive
3) measurement of surface reflectivity
4) surface friction
5) surface resistivity
6) measurement of true surface area
7) measurement of the force necessary to pull a magnet from the surface.

With all the above methods it can be argued, qualitatively, that the contour of the surface will affect the property being considered.

At the present stage of the work, only the first three methods have been examined, and two of these have been rejected. The third method, surface relectivity, does however, show considerable promise, although there are also a number of drawbacks.

Although the methods suggested above might be expected to give a direct indication of surface contour, none of them will indicate contamination, which can seriously reduce the bond strength of sprayed coatings. For this reason, some attention has been paid to methods of detecting surface oil and grease.

The measurement of the bond strength of sprayed coatings was not one of the objects of the present work; however, it has been found necessary to carry out some work on this topic due to the sparseness of the literature.

Considerable variation in results has been found in previous work, partly due to the difficulty of avoiding shear forces and partly due to problems in defining the test area. A simplication of a method covered in the Literature Review[26] has enabled a fairly quick test of bond strength to be used in the present work.

1) Measurement of surface contour

The use of a stylus for the direct measurement of surface contour is used extensively for the assessment of ground surfaces, and several machines are available. Accordingly, measurements using a Talysurf* were made on two grit blasted surfaces, one of which was known to be satisfactory and the other unsuitable for metal spraying. In practice it was found impossible to distinguish between the two surfaces, partly because the surface variation was greater than the maximum change that could be measured by the Talysurf, but mainly because the method of measurements did not show undercut in the surface. It was considered that the method could not be modified to enable the true indication of surface contour, including undercut, to be measured and no further work on this method was undertaken.

2) Adhesion

It was considered that surface condition might markedly effect the bond strength of adhesives bonded to the surface, and accordingly several tests were made to examine the joint strength of adhesives bonded to grit blasted surfaces.

In the first series of tests, a $\frac{1}{2}$ inch square of $^1/_8$ inch thick cellulose acetate was bonded to a $\frac{1}{2}$ inch diameter steel rod using an epoxy resin (Araldite). The free surface of the sheet was then wetted with acetone to cause softening, and the sheet pressed onto the grit blasted surface at known load for a specific time, using a metallurgical mounting press. The axial load to pull the cellulose acetate sheet from the blasted surface was then measured. In the original tests, a simple balance pan and weights were used but for later tests the pull-off load was measured on a 6.7 ton Denison tensile testing machine.

Considerable difficulty was experienced initially in preventing the acetate sheet from sliding along the blasted surface during loading, but this was overcome by use of a collar. At no time, however, was it possible

* Taylor-Hobson Ltd., Talysurf Model 3.

to obtain consistent, reproducible pull-off loads, even with the same test surface. Subsequent discussions with adhesives manufacturers showed that this was not surprising,* since surface preparation can have little effect on bonding of adhesive.

3) Visual inspection

Perhaps the only existing method for non-destructive assessment of a blasted surface is visual examination, which has the disadvantage of relying on human judgement. An attempt was made to improve this method by the use of low power optical microscopes both normal and stereoscopic. Use of a stereoscopic microscope showed up the blasted surface quite well, but seemed to offer little opportunity for a speedy non-destructive test.

Examination of grit blasted surfaces did show, however, that surfaces blasted at different angles and pressures, or with different types of grit, appeared to possess different surface textures. The appearance of the surface apparently depended on the diffuse reflectivity of the surface, which suggested that measurement of diffuse reflectivity might offer a suitable non-destructive testing method.

4) Reflectivity

Initial measurements of the total reflectivity of a series of grit blasted surfaces were carried out, quite crudely, using daylight and a photographic exposure meter (Weston Master III). Despite the small meter scale, it proved possible to place a series of eight grit blasted surfaces (Series I) in a reproducible order (see Table I).

Use of uniform lighting using a fluorescent tube or white light from a lamp produced the same results. The order produced by reflectivity readings correlated very closely with the bonding qualities that would be expected from the samples due to variation in blasting conditions (Table II). The samples having the best bonding qualities gave the lowest reflectivity readings. Subsequently a repeat set of specimens (Series II) was examined by using fluorescent illumination and a photographic exposure meter held at two different heights (4" and $2^3/_4$") above the specimen. The results of these tests are given in Table III. Rotation of the specimen through 90°, 180°, and 270° had little effect on the meter readings. Reasonable agreement was again found with blasting conditions, with the exception of Specimen Number 1. This was not unexpected since some dark contaminant, possibly rust, had been observed on visual examination of this specimen.

(a) Equipment

The results obtained with the photographic exposure meter were sufficiently encouraging to justify the construction of equipment specifically designed to measure surface reflectivity.

* Dr. W. Rubin, Private communication.

The first equipment utilized a Mullard phototransitor OCP71 connected in the standard Mullard circuit. The voltage output from this phototransistor was directly related to the intensity of reflected light from the illuminated specimen. This voltage was fed to a millivoltmeter via an amplifier, the reading on the amplifier giving a measure of the diffuse reflection from the test surface. Illumination in this first equipment was by means of a separate fluorescent tube. This equipment proved capable of placing the specimens of Series I and II in the same order as that obtained previously using the exposure meter and, indeed, a further set of specimens (series III) was examined satisfactorily. However, three disadvantages were observed.

1) Some drift occurred in the meter readings (see, for example, the drift of readings quoted in Table V).
2) The meter scale was too small.
3) The separate source of illumination was inconvenient and could give rise to error unless accurately controlled.

Attempts to overcome the above disadvantages were made by using a stabilised d.c. power supply, a change of meter, and by incorporating the illumination and phototransistor in a single test head. An improvement was found in the performance of this equipment but some drift still occurred, although this was much slower than found previously. Furthermore, it was found that rotation of the test head or the specimen did give a variation in reading, i.e., some specular reflection was obviously occurring. For this reason, the test head was rotated in all subsequent tests, and the maximum meter reading recorded.

Obviously the equipment was still not sufficiently stable and it was decided to adopt a different circuit. The phototransistor was replaced by a photodiode which formed one arm of a simple Wheatstone bridge, the other arms being high stability resistors. A variation in the intensity of the reflected light falling on the photodiode produces in the bridge an out of balance voltage. The stabilising circuit was discarded and the amplifier and voltmeter replaced. In addition, it was decided to standardise the meter reading, before each test, on a piece of white paper.

In its present form the equipment consists of two separate assemblies (Figure 3 and 4).

1) The sensing head
2) A carrying case containing the amplifier and voltmeter.

The sensing head (Figure 4), which is contained in a 2″ diameter, 6″ long light alloy tube, contains the light source, photodiode, and bridge circuit with its associated power supply. The light source consists of a lens-end lamp rated at 2.2 volts a.c., although it is actually operated at 1.7 volts to increase life. Power is supplied from a mains transformer located in the carrying case and a potentiometer in the circuit allows corrections of fluctuation in mains voltage to be made. The photodiode used is a Mullard type OAP12; values of resistors in the bridge circuit are shown in Figure 3. Power supply to the bridge is by means of a 1.5 volt dry cell, operating through a potential divider.

The voltage output from the bridge is fed through a co-axial cable to the transistorized d.c. amplifier, designed by Texas Instruments Ltd.* Amplifier power is supplied by two 12 volt dry cells. The amplifier gain can be adjusted by means of a potentiometer between the emitters of the first two transistors, enabling the equipment to be standardised (see below). The output from this amplifier is sufficient to operate an Avometer Model 8 operating on the 10 volt scale.

(b) Testing procedure

The testing procedure for the grit blasted surfaces was kept as simple as possible, as it would need to be for site inspection. The power supply to the equipment was switched on and the meter reading adjusted to a calibration mark by placing the sensing head on a piece of white paper. This standardising procedure was carried out before each test reading, in order to compensate for drift. The sensing head was then placed against the test surface and turned until the meter gave a maximum reading, which was noted.

This testing procedure enables a set of samples to be placed in order of reflectivity and also gives reasonably consistent and reproducible meter readings.

(c) Results

Reflectivity results for two series of seven specimens are given above. A further three series of specimens have been received and examined, using the equipment described above.

Series III consisted of eight specimens blasted under conditions given in Table IV. These specimens had been partially sprayed and the results of bond pull-off tests (see below) are also given. The results of reflectivity readings are given in Table V, from which it can be seen that there is a good consistent relationship between blasting conditions and reflectivity. Bond strength also follows the expected pattern. Examination of sections of these specimens with the optical microscope shows a relationship between surface roughness and blasting conditions (Figures 5a and 5b).

Series IV contained seven specimens (Table VI), but two of these specimens (Numbers 6 and 7) have been ignored since they were blasted several times with blunt grit until the operator considered that the surface was suitable for spraying. Reflectivity readings are given in Table VII. The results show the consistency of the equipment, provided it is standardised before each reading. Results for side 'a' are particularly good, in that very little overlap occurred in the readings for different specimens, even over a period of time. The exceptions were specimens 3 and 4, which

* Texas Application Note 8, Texas Instruments Ltd., Bedford.

could not be distinguished by the reflectivity test.

The final series of specimens examined so far, Series V, does not, unfortunately, support the encouraging results obtained on previous specimens. This series, for which blasting conditions are given in Table VIII, had a markedly different appearance from previous series, and some doubts were expressed when the specimens were first received, surface contamination being considered a possibility. For this reason the specimens were examined in both the 'as received' and 'scratch brushed' conditions. The results of reflectivity tests (Table IX) show no correlation with blasting conditions. It is also interesting to note that the level of reflectivity readings is markedly lower for Series V than for Series IV, despite the fact that the same method of standardisation was used.

5) Bond strength of sprayed surfaces

At an early stage in the work it became obvious that some qualitative measurement of the quantity of the sprayed bond was desirable. Several methods of measuring bond strength have been reported in the literature, although in many cases experimental results have been rather inconsistent.

After some consideration it was decided to measure the 'pull-off' strength of the coating, using a method similar to that of Smith and Stephenson, but taking precautions to avoid shearing, which appeared the most likely cause of their erratic results.

The procedure adopted was to machine away part of the sprayed surface of the specimen, leaving a raised boss of $1^{1}/_{16}$ inches diameter (Figure 6). A 2 inch long steel rod was then bonded to the sprayed surface of the boss with an epoxy resin adhesive (Araldite), considerable care being taken with the alignment of the boss and rod. After curing the Araldite, the boss and rod were machined to 1 inch diameter and mounted in the test rig shown in Figure 7. This test rig, of mild steel, was carefully machined to ensure that, when mounted in a tensile testing machine, a vertical load would be applied to the sprayed metal bond.

Results of 'pull-off' tests are quoted in Tables IV, VI, and VII. In the cases of Series III and IV, reasonable agreement was found between bond strength and the surface quality as measured by the reflectivity test, but no correlation was found for Series V. Several specimens failed before machining, due to poor bond strength.

No comparison is permissible between bond strengths obtained for the different series since Series III was sprayed immediately after grit blasting, whereas the other series were not sprayed for several days (although specimens were kept in a dessicator).

Surface contamination

Surface oil or grease can be a serious problem with blasted surfaces since it can be readily introduced by dirty grit or a faulty compressed air supply. Small amounts of grit on the surface may have little effect on the sprayed coating, but larger quantities would certainly reduce the bond strength. The reflectivity test is unlikely to detect surface contamination and it was therefore considered imperative that another simple test for surface oil should be obtained. Three of the tests reported in the literature survey have been applied to blasted surfaces.

1) Water drop
2) Basic fuchsin
3) Solvent.

If a drop of water is applied to a smooth metal surface, the water will spread if the surface is free from oil, but will otherwise remain as a drop. This method proved to be inapplicable to a rough blasted surface since the water tended to spread whether oil was present or not.

The use of the basic fuchsin method was also unsuitable for the present application. This method did, in fact, show up the presence of oil or grease, but it left the whole surface contaminated and slightly coloured. Thus if this method was used, a further cleaning treatment would be necessary before spraying.

The suggestion that a drop of solvent, if placed on the test surface and allowed to evaporate, would show a dark ring around the edge of the drop if oil or grease was present has the advantages of simplicity and speed, whilst no subsequent treatment is necessary. Initial experiments using trichlorethylene have proved very successful, although further tests are needed finally to prove the test.

Discussion of results

The results obtained in the first six months work indicate that the reflectivity test offers a reasonable chance of success. The main problems lie in correlating blasting conditions and reflectivity readings with conditions, and reflectivity readings with bond strength. The use of small numbers of specimens are unlikely to help this correlation and it is hoped to test several hundred samples in the next three months. Detection of surface oil and grease by the solvent method is extremely promising although further proving tests are necessary.

Methods for the assessment of grit blasted surfaces other than the reflectivity method have received little attention. Future work will continue to concentrate on the reflectivity test but it is hoped that some of the other methods may be explored.

The work on the measurement of bond strength has suggested a possible method for the testing of sprayed coatings. If an acceptable minimum 'pull-off' strength can be established the use of a simple 'pull-off' test using a portable tensile testing machine and an adhesive that fractures at or just below the minimum 'pull-off' strength, the test would be destructive for unsuitable coatings but non-destructive for satisfactory coatings. At present the literature is being examined to determine which adhesives exhibit suitable strengths and have very short curing times.

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Daylight	White Light	Fluorescent Light	Mean	Rating*
5	5	5	5	5
6	1	1	1[H]	1
7	6	7	7[H]	6
1	7	6	6[H]	7
2	4	2	2	2
3	2	3	3	4
4	3	4	4	3

* This is the rating of increasing bond strength given by the suppliers of the samples.

H Little variation in reflectivity could be detected in these specimens.

TABLE I Specimens placed in order of decreasing reflectivity for series I grit blasted samples

Specimen Number	Blasting Conditions		
	Nozzle Angle	Blasting Pressure p.s.i.	Abrasive
5	15°	60	Blunt Steel Grit
1	15°	60	New Chilled Iron Grit
6	60°	60	Blunt Steel Grit
7	90°	60	Blunt Steel Grit
2*	60°	60	New Chilled Iron Grit
4*	90°	30	New Chilled Iron Grit
3	90°	60	New Chilled Iron Grit

* No difference in bond strength would be anticipated in these two specimens.

TABLE II Blasting conditions for seven grit blasted samples (Series I and II) in order of increasing bond strength.

Meter held 4 inches above specimen					Meter held $2^3/_4$ inches above specimen					Rating*
0°	90°	180°	270°	Mean	0°	90°	180°	270°	Mean	
7	5	5	5	5	5	5	5	5	5	5
5	7	7	7	7	7	7	7	7	7	1
6	6	6	6	6	6	6	6	6	6	6
2	2	2	2	2	1	1	1	1	1	7
3	3	3	3	3	2	2	2	2	2	2
1	1	1	1	1	3	3	3	3	3	4
4	4	4	4	4	4	4	4	4	4	3

* Rating of increasing bond strength given by the suppliers of the samples.

TABLE III Order of decreasing reflectivity for Series II Grit Blasted samples.

Specimen Number	Blasting Conditions			Bond strength p.s.i.
	Nozzle Angle	Blasting Pressure p.s.i.	Abrasive	
6	90°	60	New Chilled Iron Grit	855
2	90°	30	New Chilled Iron Grit	1140
8	90°	30	New Chilled Iron Grit	998
3	60°	60	New Chilled Iron Grit	969
5	15°	60	New Chilled Iron Grit	599
4	90°	60	Blunted Steel Grit	Failed during machinery.
1	60°	60	Blunted Steel Grit	413
7	15°	60	Blunted Steel Grit	Failed before machining.

TABLE IV Blasting conditions and bond strength for Series III, in order of improving surface preparation.

Specimen No.	Readings on Meter												1
	1	2	3	4	5	6	7	8	9	10	11	12	
6	9.39	9.38	9.42	9.42	9.45	9.50	9.50	9.50	9.52	9.51	9.52	9.51	
2	9.34	9.35	9.40	9.40	9.41	9.45	9.45	9.48	9.49	9.49	9.50	9.49	
8	9.32	9.35	9.35	9.40	9.42	9.41	9.45	9.49	9.49	9.49	9.50	9.50	
3	9.28	9.29	9.30	9.35	9.36	9.38	9.39	9.39	9.40	9.46	9.45	9.45	
5	9.21	9.21	9.22	9.30	9.31	9.32	9.32	9.32	9.38	9.38	9.40	9.40	
4	9.19	9.20	9.22	9.28	9.30	9.30	9.31	9.30	9.35	9.25	9.38	9.39	
1	9.10	9.12	9.15	9.19	9.19	9.25	9.25	9.25	9.28	9.25	9.29	9.29	
7	9.09	9.10	9.11	9.19	9.20	9.20	9.21	9.20	9.22	9.28	9.28	9.29	

Specimen No.	13	14	15	16	17	18	19	20	21	22	23	2
6	9.58	9.60	9.19	9.50	9.50	9.50	9.51	9.51	9.51	9.51	9.51	
2	9.55	9.55	9.11	9.49	9.48	9.47	9.48	9.48	9.49	9.49	9.48	
8	9.55	9.55	9.11	9.48	9.48	9.48	9.48	9.49	9.48	9.49	9.48	
3	9.49	9.49	9.10	9.38	9.35	9.38	9.39	9.38	9.38	9.39	9.38	
5	9.41	9.44	9.00	9.30	9.30	9.31	9.31	9.31	9.32	9.33	9.32	
4	9.39	9.41	8.89	9.29	9.28	9.29	9.30	9.30	9.31	9.31	9.31	
1	9.31	9.32	8.90	9.13	9.15	9.18	9.19	9.19	9.19	9.20	9.19	
7	9.31	9.31	8.89	9.10	9.10	9.09	9.14	9.11	9.11	9.13	9.11	

TABLE V Order of decreasing surface quality for series III grit blasted specimens

Specimen Number	Blasting Conditions				
	Nozzle Angle	Blasting Pressure p.s.i.	Abrasive	Bond Strength, p.s.i. Side A	Side B
1	90°	60	New Angular Steel Grit	770	570
5	90°	30	New Angular Steel Grit	513	Failed
2	45°	60	New Angular Steel Grit	285	285
3	30°	60	New Angular Steel Grit	342	Failed
4	15°	60	New Angular Steel Grit	285	356
6*	90°	60	Well Worn Steel Grit	485	684
7*	15°	60	Well Worn Steel Grit	342	456

* Specimens were blasted three times by the operator until he considered the surface suitable for spraying.

TABLE VI Blasting conditions and bond strength for Series IV, in order of decreasing surface quality

Specimen Number	Test Number and Side 1a	2a	3a	4a	5a	6a	1b	2b	3b	4b	5b	6b
6	4.25	4.50	4.60	4.60	4.75	4.80	4.75	4.50	5.00	5.00	4.50	5.00
7	5.75	5.60	5.70	5.75	5.75	6.00	6.00	5.75	6.25	6.00	6.00	6.25
1	6.50	6.40	6.60	6.50	6.60	5.75	6.50	6.50	6.75	6.75	6.50	6.60
5	6.75	6.75	7.20	7.00	7.00	6.75	7.75	7.50	7.25	8.00	8.00	8.00
2	7.80	7.75	8.25	8.00	8.00	8.00	8.50	8.50	8.50	8.70	8.75	8.70
3	9.25	9.50	9.25	9.75	9.80	9.60	8.00	7.75	8.00	8.30	8.50	8.50
4	9.25	9.75	9.50	9.50	9.75	9.50	8.25	7.80	8.25	8.25	8.75	8.50

TABLE VII Reflectivity results for Series IV in order of decreasing surface quality.

Specimen Number	Blasting Conditions				
	Nozzle Angle	Blasting Pressure p.s.i.	Abrasive	Bond strength p.s.i.	
				As received	Scratch Brushed
1	90°	60	New Grit	Failed	Failed
5	90°	45-50	New Grit	Failed	Failed
2	60°	60	New Grit	314	256
4	90°	30	New Grit	Failed	Failed
6	90°	57.5	Poor Grit with Rounds	228	256
7	60°	57.5	Poor Grit with Rounds	314	Failed
9	90°	45-50	Poor Grit with Rounds	456	Failed
8	90°	30	Poor Grit with Rounds	Failed	Failed
3	15°	60	New Grit	199	Failed
10*	90°	60	New Grit	399	Failed

* Specimen greased prior to blasting.

TABLE VIII Blasting conditions for Series V, in order of decreasing surface quality

(A) As received	Test Number						
Specimen Number	1	2	3	4	5	6	Average
9	2.1	2.1	2.1	2.0	2.2	2.1	2.1
8	2.3	2.3	2.2	2.2	2.0	2.3	2.2
6	2.1	2.3	2.2	2.1	2.2	2.1	2.2
7	2.3	2.3	2.4	2.3	2.3	2.2	2.3
5	2.5	2.6	2.5	2.3	2.4	2.5	2.5
4	3.4	3.5	3.4	3.4	3.3	3.5	3.4
10	3.6	3.7	3.6	3.7	3.5	3.7	3.65
1	3.7	3.8	3.7	3.6	3.5	3.7	3.7
2	3.8	3.9	3.8	3.9	3.9	3.8	3.85
3	4.1	4.3	4.2	4.1	4.3	4.1	4.2
(B) Scratch Brushed							
Specimen Number	1	1	3	4	5	6	Average
6	5.4	5.2	5.2	5.2	5.0	5.1	5.2
7	6.0	5.8	6.0	5.9	5.8	5.8	5.9
1	6.2	6.3	6.4	6.2	6.4	6.4	6.3
5	6.5	6.6	6.6	6.4	6.4	6.5	6.5
10	6.3	6.6	6.7	6.5	6.5	6.8	6.6
2	7.0	7.1	7.0	7.0	7.0	7.0	7.0
9	7.1	7.2	7.2	7.1	7.1	7.2	7.15
3	7.2	7.2	7.2	7.2	7.3	7.4	7.25
8	7.6	7.6	7.4	7.4	7.4	7.4	7.5
4	7.6	7.6	7.4	7.6	7.4	7.5	7.5

TABLE IX Reflectivity results for Series V in order of decreasing suface quality

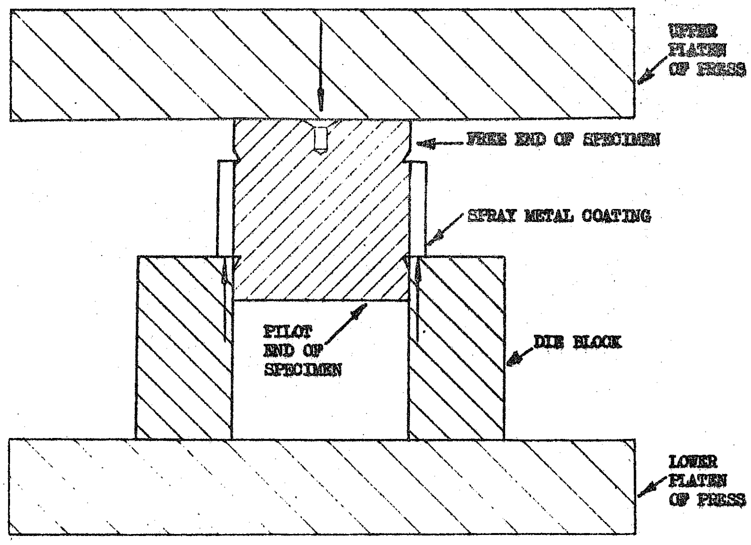

UPPER PLATEN OF PRESS
FREE END OF SPECIMEN
SPRAY METAL COATING
PILOT END OF SPECIMEN
DIE BLOCK
LOWER PLATEN OF PRESS

FIG. 1a

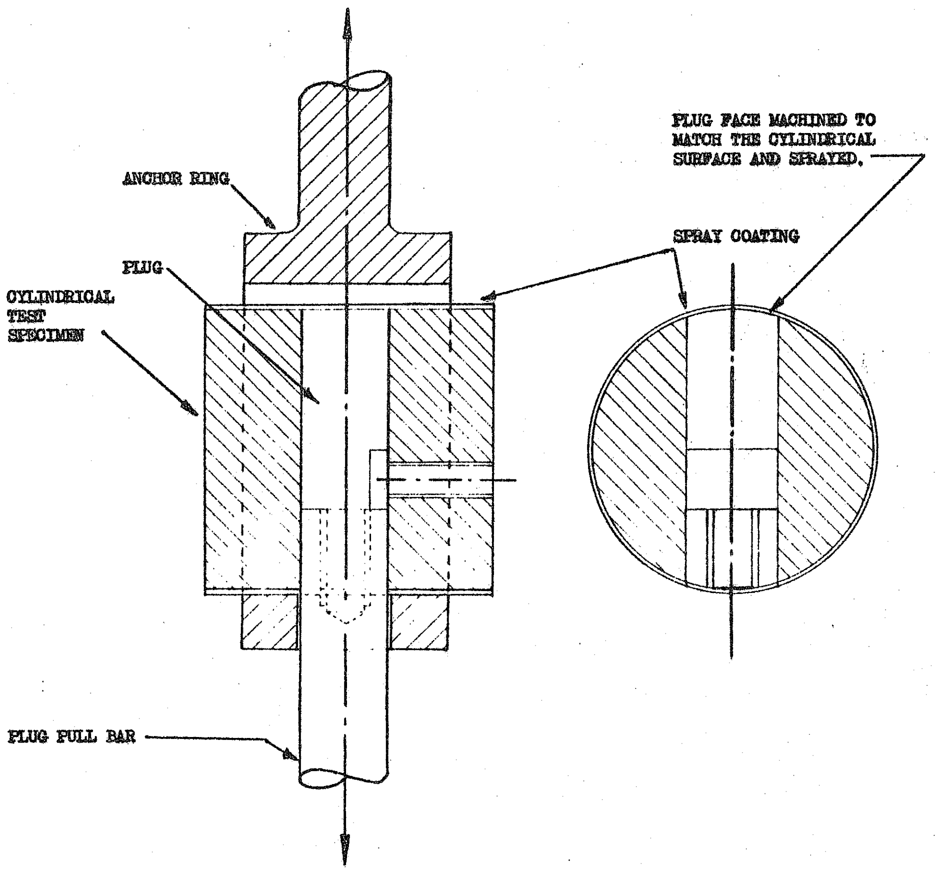
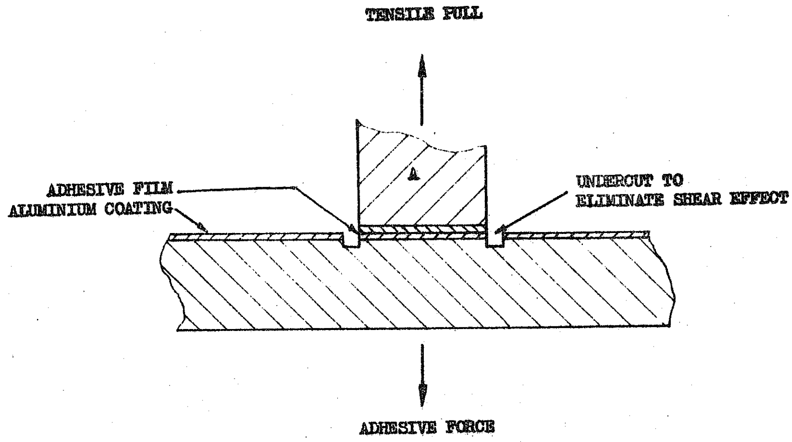
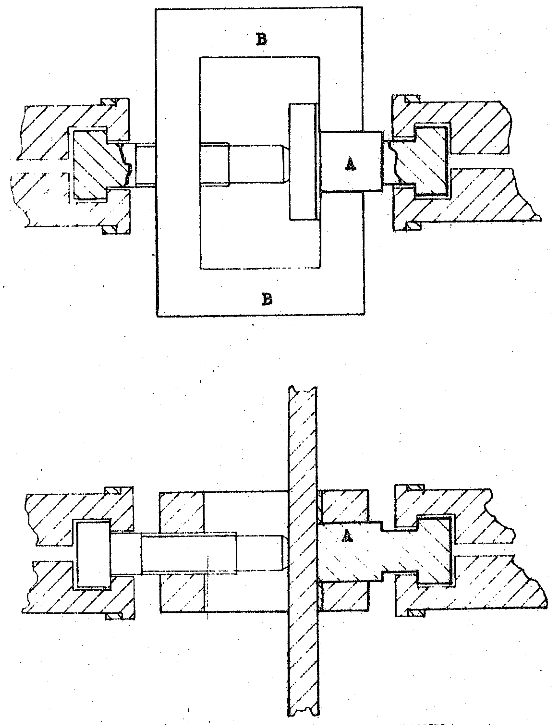

PLUG FACE MACHINED TO MATCH THE CYLINDRICAL SURFACE AND SPRAYED.
ANCHOR RING
SPRAY COATING
PLUG
CYLINDRICAL TEST SPECIMEN
PLUG PULL BAR

FIG. 1b

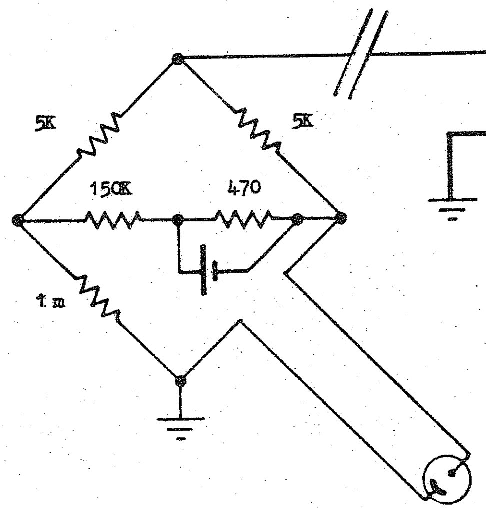


SKETCH OF METHOD USED FOR TESTS.



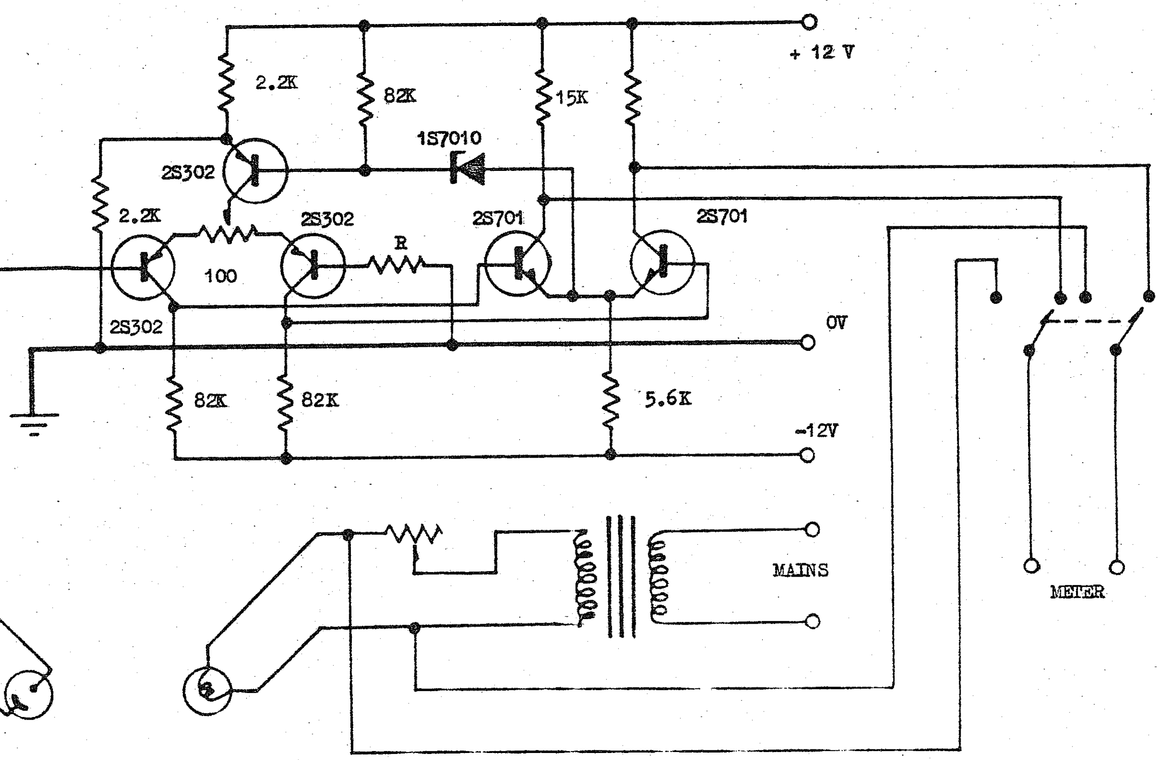
LABORATORY TEST FOR ADHESION.

FIG. 2



5K
5K
150K
470
1 m

Fig. 4



+ 12 V
2.2K
82K
15K
1S7010
2S302
2.2K
2S302
2S701
2S701
100
R
2S302
0V
82K
82K
5.6K
-12V
MAINS
METER

Fig. 3

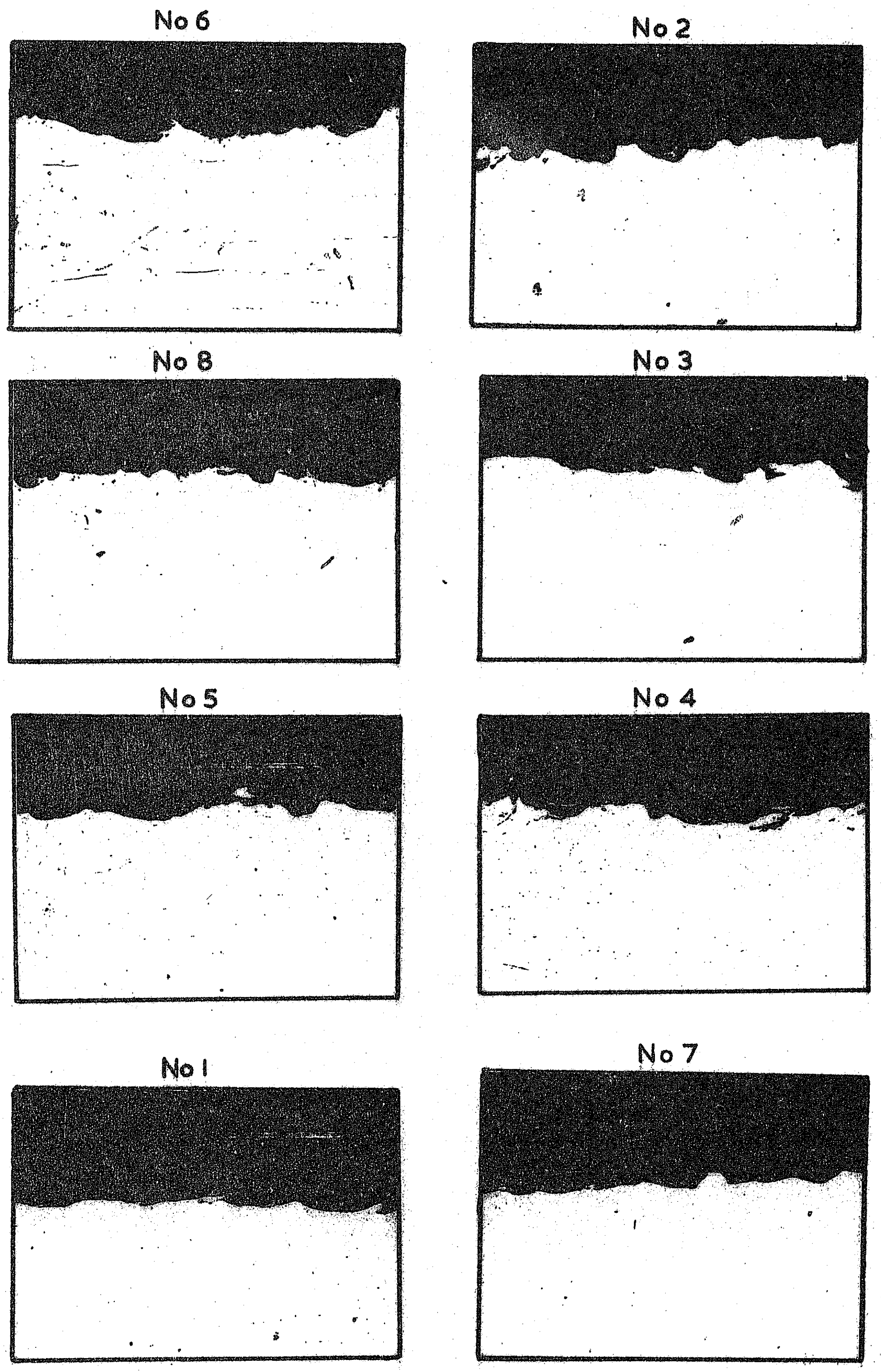


FIG 5a: GRIT BLASTED SPECIMENS - SERIES III: SURFACE CONTOUR & DEPTH ACROSS THE LENGTH OF SPECIMENS PLACED IN THE ORDER OF DECREASING SURFACE QUALITY [REF: TABLE V]

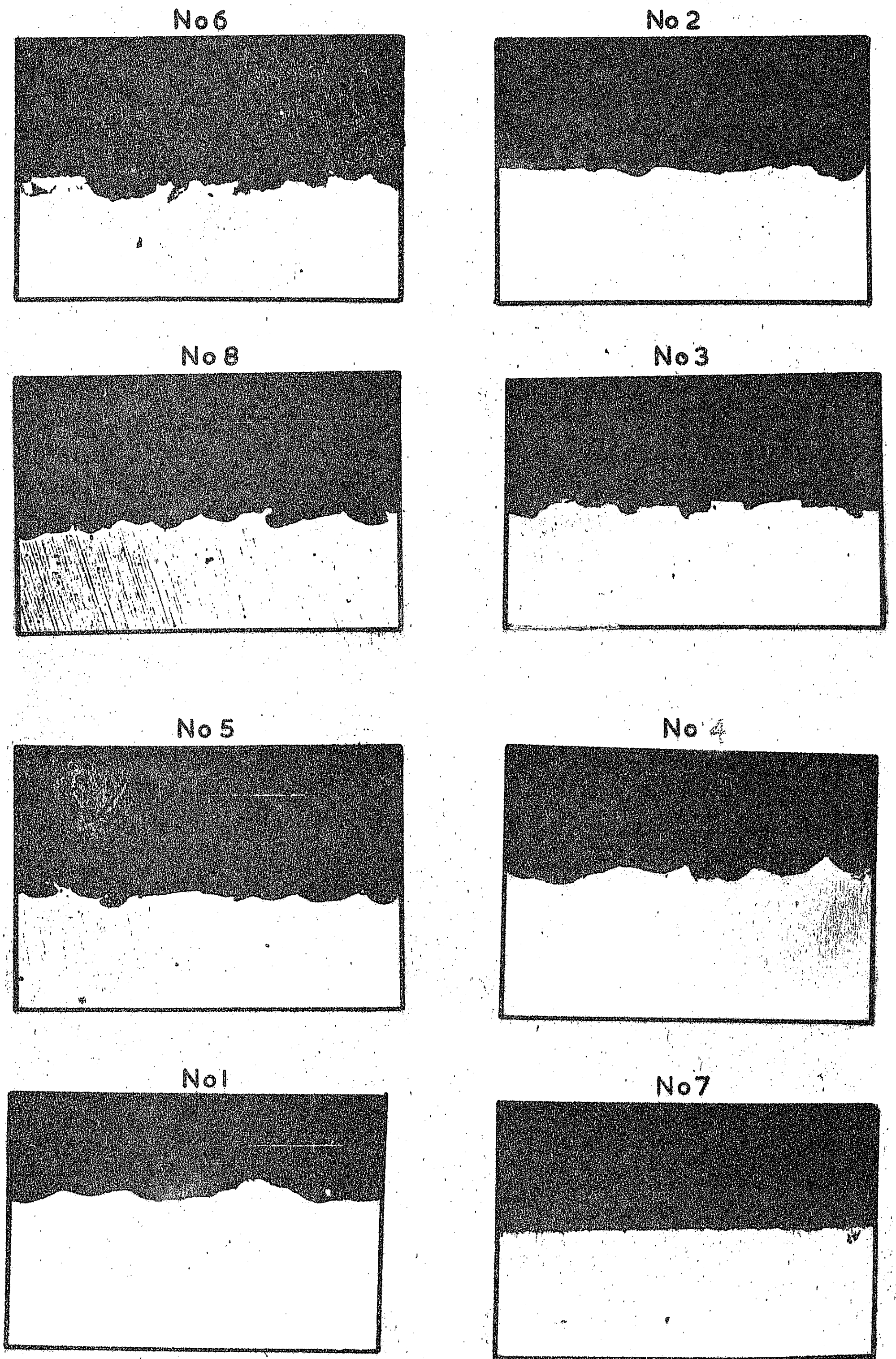
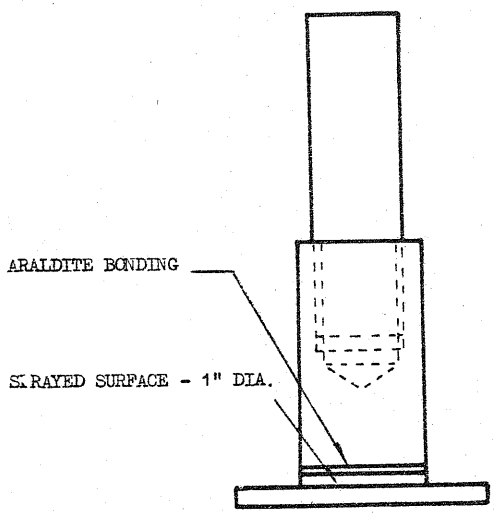


FIG 5b: GRIT BLASTED SPECIMENS - SERIES III: SURFACE CONTOUR & DEPTH ACROSS THE WIDTH OF SPECIMENS PLACED IN THE ORDER OF DECREASING SURFACE QUALITY [REF: TABLE V]



TEST SPECIMEN.

Fig. 6

SKELETON SKETCH FOR 'PULL-OFF' TEST.

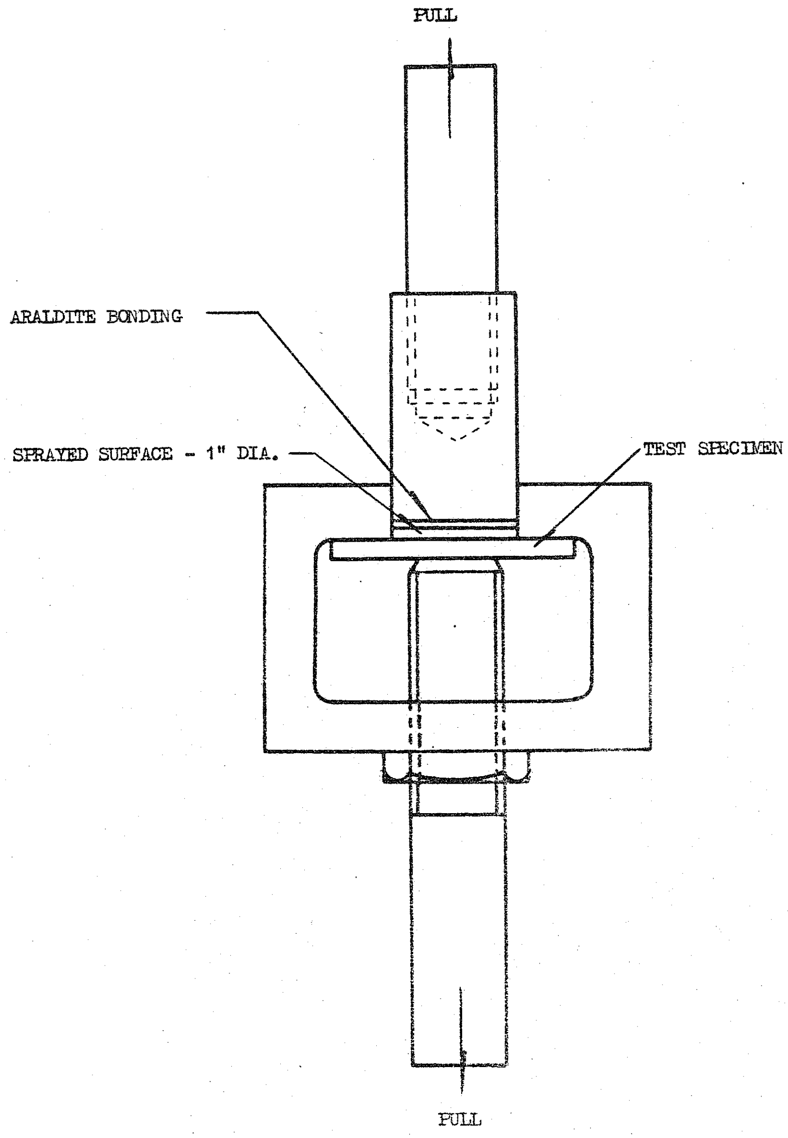


Fig. 7