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THE COLLEGE OF AERONAUTICS

CRANFIELD

ASSESSMENT OF BLASTED SURFACES PROGRESS REPORT No. 3

by

R. L. APPS

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DEPARTMENT OF MATERIALS

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Introduction

This report covers work carried out from January - August, 1964. The work has largely consisted of further tests with the Cranfield reflectivity equipment and associated measurements of pull-off strength, but a brief assessment has also been made of an instrument for measuring reflectivity developed by the Paint Research Station. A number of miscellaneous tests are also reported. The final months of the period covered by the report have been spent in the design and construction of a new reflectivity instrument which incorporates features that the previous instruments have shown to be desirable.

Particular topics reported cover the effect of grit size and blasting time, and also a determination of the effect of using light sources of specific colours instead of white light. Much of this work has been done at laboratories and works away from Cranfield to allow external assessment of the reflectivity equipment. A number of miscellaneous tests have also been made covering the use of non-metallic grits and 'Jason' type hammers for surface preparation, the assessment of sprayed coatings by a simple bend test and the examination of the variation of strength with time of two adhesives to determine whether an adhesive could be used for practical site testing of sprayed coatings.

Equipment

All reflectivity tests were carried out with the equipment described in Progress Report No. 2, with the exception of the work at the Paint Research Station, which utilised an EEL instrument. This instrument operated on the same general principles as the Cranfield instrument.

Materials

Except for reflectivity measurements on commercial components all tests were carried out on mild steel conforming to the requirements of BS 2569: Part 1:1955. Where tests of bond strength were required the test surfaces were sprayed with aluminium.

Experimental

(i) Surface preparation

Grit blasting was carried out by three separate companies in accordance with conditions laid down by Cranfield. Series A and B (Table I) were prepared in a small manual blasting cabinet which enabled a close control to be applied whilst Series C - F (Table I) and I and II (Table II) were prepared in a larger, manually operated machine which did not allow such close control of blasting angle, although blasting time could be recorded with reasonable accuracy. The trials listed in Table IV were carried out under commercial conditions using either large manual or automatic blasting cabinets, which allowed only nominal control over the operator.

Two surfaces were also prepared for examination using a 'Jason' type hammer.

(ii) Visual inspection

All specimens were examined visually to ensure complete removal of scale, absence of oil, etc.

(iii) Reflectivity

Reflectivity was measured by the same procedure as that given in Progress Report No. 2: in cases where other than white light was required a coloured filter was fixed in front of the lamp with an adhesive.

The EEL instrument developed by the Paint Research Station had a greater sensitivity than the Cranfield instrument and clearly showed directional effects. For this reason four readings were taken on each specimen, i.e. maximum and minimum reflectivity readings, and reflectivity in the longitudinal and transverse directions of the test specimen. The Paint Research Station used a blue light source in this instrument. The EEL instrument exhibited the same tendency to drift that had been found with the Cranfield instrument and, if anything, required more frequent correction.

(iv) Spraying

Where pull-off tests were to be made the specimens were sprayed with aluminium to a coating depth of approximately 0.005 inch. The coating depth was checked only in the case of specimens listed in Table IV. Spraying was carried out immediately after blasting except for Series C, E and F (Table I) Series II (Table II) and Series I (Table VII). In these cases specimens were sealed in polythene after blasting and sprayed later at Cranfield.

(v) Strength tests

Pull-off tests for bond strength were carried out using the procedure detailed in previous Progress Reports.

Testing of the two adhesives (Eastman Kodak 910 and Kelseal 334) was also carried out on a tensile testing machine. In these cases two 1 inch diameter steel bars were bonded with the adhesive and, after a specified time at room temperature for bonding, the cylinders were pulled apart in a Denison testing machine. Care was taken to ensure the straightness of the cylinders to give a pure tensile load on the assembly.

(vi) Examination of blasting media

In certain cases samples of the grit used for blasting were photographed under a low power microscope to allow an assessment of quality. Typical photographs are shown in figures 1 - 5.

Results

(i) Influence of time of blasting

The influence of blasting time on reflectivity and pull-off strength is given in Table I for three grit sizes. Neither reflectivity nor strength show a consistent variation, particularly at shorter blasting times, although at longer times there is an indication that reflectivity increases (Fig. 6).

(ii) Grit size and appearance

The results for different sizes of grit are shown in Table II. Results for Series I and II exhibit considerable scatter and indicate no obvious trend but it is suggested that the results of Series I are erroneous since the reflectivity figures obtained for G24 grit do not agree with figures obtained in other test series. If Series II is considered alone there is an indication that reflectivity increases slightly with grit size; however, results are too few for positive conclusions. In all cases reflectivity increases with decreasing blast angle.

Typical samples of the grits used for blasting are shown in Figures 1 - 5. The new grits, although nominally angular, all contain a considerable proportion of rounds. A comparison between G24 new and used grit (Figures 2 and 5) shows that the used grit contains a fair proportion of small rounded particles.

(iii) Light source

The results of using red, blue and yellow filters for reflectivity tests on Series C, E and G are given in Table III. No significant advantages were observed over white light.

(iv) External trials

The results of tests on specimens prepared in commercial grit blasting cabinets (and subsequently sprayed after testing) are given in Table IV. Reflectivity readings indicate acceptable surfaces in all cases and pull-off tests support this indication.

The reflectivity equipment performed reasonably well during external trials at four locations, although variation in local mains voltage did have an effect.

(v) Tests made at the Paint Research Station

The results of reflectivity tests made at the Paint Research Station, using equipment developed by them (EEL instrument) and the Cranfield equipment, are presented in Table V and summarized in Table VI. Both instruments show the same trend as previously observed at Cranfield, although the EEL instrument had the greater sensitivity: the best agreement was obtained when the maximum reading of the EEL instrument was taken. The range of readings (maximum to minimum) with the EEL instrument gave a correlation with blasting angle, the range increasing with decreasing angle. This increasing directionality would be expected but is not clearly revealed by the Cranfield instrument.

The readings obtained from the Cranfield instrument showed considerable discrepancies from what was expected from the blasting conditions. Readings were generally high and specimens blasted with blunt grit had lower reflectivities than those blasted with new angular grit. The reason for these discrepancies is not known.

(vi) Miscellaneous tests

A number of miscellaneous tests of secondary importance have been undertaken during the period under review; results are reported below.

(a) Surface preparation with non-metallic grits

The results of reflectivity and pull-off tests for surfaces blasted with non-metallic grits are presented in Table VII. These tests show that reflectivity is unsuitable for assessing the quality of surfaces prepared by this method. The bond strengths of aluminium coatings on these specimens were low.

(b) Surface preparation with a 'Jason' type hammer

Two trial surfaces prepared by this method had a high reflectivity and would be classified as unsuitable for metal spraying. Visual examination under a low power stereoscopic microscope offered confirmation of this view since the surfaces, although clean, were very little roughened compared to a grit blasted surface.

(c) Bend tests

In view of the tedious preparation necessary for pull-off test specimens an examination was made of the suitability of free and guided bend tests for assessing coating adhesion. All except the poorest coatings proved capable of extensive deformation and bend tests proved incapable of detecting variations in coating adhesion.

(d) Standardisation of reflectivity equipment

The Cranfield reflectivity equipment is standardised on a piece of clean white paper and it has generally been considered that the quality of the paper had little effect. Trials were carried out on a number of different types of white paper, including gloss and matte papers, and these were shown to have virtually no effect on the subsequent readings given by the instrument. This is, of course, a measure of the insensitivity of the equipment and it is interesting to note that the EEL instrument was standardised on a glossy grey tile of controlled reflectivity.

(e) Variation of bond strength with time of two adhesives

The variation of strength with time of two adhesives is given in Table VIII. The strength of Eastman Kodak 910 increases fairly consistently with time up to 16 hours, although some scatter in results was observed. Kelseal 334 showed zero strength for periods up to 8 hours and only low strength after 22 - 48 hours. It must be remembered that Kelsey Industries Ltd. stated that Kelseal 334 was unlikely to be suitable.

Construction of new reflectivity equipment

Over the latter part of the period under review a new instrument for measuring reflectivity has been designed and built. This instrument, which is extremely compact, is battery operated to allow its use on site work; the stability has also been improved and sensitivity increased. Further details of this instrument will be given in the next report, together with details of field trials.

Discussion

Many of the results obtained in the present series of tests are inconclusive and further work is required for clarification. In particular, more results are needed on the influence of blasting time, grit size and colour of light source. However, the correlation of surface reflectivity of a grit blasted surface with its suitability for metal spraying has been further supported and justifies further work.

The results for the effect of blasting time on reflectivity and pull-off strength (Figure 6) do not show any strong trend. This is in disagreement with work carried out by the Paint Research Station which shows a marked increase in reflectivity with blasting time for the shorter times, before the reflectivity approaches a constant value. Although grit blasting is normally only carried out for a few seconds before metal spraying it is important to clarify this point and further trials will be carried out.

Again, the number of results obtained for the effect of grit size on reflectivity and pull-off strength (Table II) are insufficient to show any strong trend although reflectivity does appear to increase with decreasing grit size. In all cases the reflectivity increases with decreasing angle of blasting, thus supporting the results found previously with G24 grit. Insufficient results are available to determine the effect of grit size on bond strength.

The trials with coloured light sources failed to show any marked advantage over white light. It is proposed to continue with these tests however, to check whether coloured light gives an advantage in service or on contaminated surfaces. The EEL instrument, it may be noted, utilizes blue light since the Paint Research Station feels that this minimises the influence of surface rust on the reflectivity. Since rust is undesirable for sprayed surfaces and can be detected by visual examination, this requirement is of little significance in the present work.

External trials of the reflectivity equipment indicated that the general design could be used in the field, although the reliance on an external electrical power supply was obviously undesirable. This has resulted in a re-design of the equipment to allow battery operation and to increase its compactness.

The external trials also indicated another interesting point: even in small blasting cabinets accurate control of the blasting angle was quite difficult and in large commercial cabinets no more than nominal control could be exercised. Thus reflectivity figures in several instances were lower or higher than would be expected from previous work. It was therefore gratifying in the case of the work summarised in Table IV to find that reflectivity and bond strength remained in reasonable agreement. Work nominally blasted at 15° in a commercial cabinet gave a low and acceptable reflectivity whilst the pull-off strength of the subsequently sprayed coating was in agreement with the reflectivity. Many more results are obviously needed but it does appear that reflectivity figures give a true indication on the bond strength that can be obtained on subsequent spraying.

The photographs of various grit samples are also extremely interesting. The new unused grits (Figures 1 - 4) all show a considerable proportion of rounds, which are presumably useless in preparing a desirable surface. This might be considered to indicate that angular grit with fewer rounds should be required of the manufacturer, but the illustration, Figure 5, of used 24 grit (not connected with any samples recorded in this report) provokes the speculation whether this would, in fact, lead to an improvement in the quality of blasted surfaces. This used grit from a commercial blasting cabinet contains a high proportion of fine material and much of the grit is blunted. This illustration is believed to be typical of much of the grit used in commercial plants and leads to the conclusion that grit control is at present overlooked by many commercial blasters and sprayers. It should, perhaps, be emphasized that adequate surfaces (as measured by reflectivity) can be obtained with this grit if care is taken by the blaster, but reflectivities are generally higher than those obtained with new angular grit.

The relationship of pull-off strength with reflectivity, exhibited by specimens tested over the last 15 months, is displayed in Figure 7. This figure includes all the results obtained with specimens blasted with angular and blunted grit, but not those of specimens prepared with dirty grit (i.e. specimens MA, MF, MJ in Series B, Progress Report No. 2). These results show the expected decrease in bond strength with increasing reflectivity, but considerable scatter is obtained. The results are contained in a well-defined envelope and specimens blasted under good conditions (to give a reflectivity of 4.3 to 5.0 on the arbitrary scale) will generally give pull-off strengths after spraying in excess of 600 p.s.i. Alternatively, specimens blasted under poor conditions (and showing reflectivities over 5.4) result in sprayed aluminium coatings with low bond strength, although occasionally strengths up to 800 p.s.i. are found.

The scatter range must lead to a consideration of the experimental method. Considerable care is taken during machining and testing to avoid impact and bending loads, nevertheless a possibility must always exist that loading during machining could result in premature failure of the bond. An alternative suggestion is that the inherent residual stresses in sprayed coatings are sufficient to give all, or most of, the observed scatter, and this is supported by the wide scatter reported by other workers. In the present work, the coating thickness and base metal temperature has not been closely controlled and this could well add variation in residual stresses.

A more basic issue is the value of bond strength measurements. The ultimate criterion must be the service performance of the sprayed coating and in the case of aluminium and zinc coatings this means the corrosion protection afforded by the coating. It is obvious that there must be bonding between the coating and base metal to prevent spalling, but what level of bond strength is necessary is by no means clear. If, for example, a strength of 200 p.s.i. is sufficient then present good industrial practice is adequate, but if a strength of, say, 1000 p.s.i. is necessary than it is doubtful if even the best commercial practice is good enough, or that it could be made good enough without expensive additional control. The case has probably been overstated, but it is important to consider the exact significance of pull-off tests. It may be that a simple corrosion test would provide more worthwhile information and there is certainly a need to correlate laboratory tests with performance in service.

TABLE I Influence of blasting time on reflectivity of blasted surfaces, together with pull-off strengths of Al coatings subsequently sprayed on these surfaces.

Series	Blasting Conditions				Reflectivity				Pull-off Strength p.s.i.
	Time, Seconds	Grit	Angle°	Pressure p.s.i.	1	2	3	Mean	
A	7.5	G24C.I	60	60	4.5	4.4	4.6	4.50	1174
	11.5				4.65	4.6	4.6	4.62	740
	15				4.5	4.5	4.5	4.50	1134
	15				4.45	4.65	4.45	4.52	1202
	22.5				4.5	4.6	4.5	4.53	729
	30				4.7	4.4	4.4	4.50	541
	75				4.1	4.6	4.2	4.30	798
	150				4.7	4.8	4.8	4.77	854
B	15		15		5.3	5.4	5.7	5.47	363
	30				5.5	6.0	5.5	5.67	0
	150				5.8	5.6	5.7	5.70	541
C *	14	G24C.I	90	60	4.8	4.7	4.8	4.77	398
	28				4.4	4.6	4.6	4.53	968
	60				4.6	4.6	4.6	4.60	546
	240				4.8	4.9	5.0	4.90	584
	360				5.3	5.4	5.4	5.37	620
D	14	G24C.I	90	60				4.20	-
	28							4.30	-
	42							4.20	-
	56							4.40	-
	120							4.60	-
	240							4.40	-
E	14	G17C.I	90	60	5.0	5.0	5.0	5.00	688
	28				5.5	5.4	5.4	5.43	305
	60				5.6	5.5	5.5	5.53	404
	240				6.0	6.4	6.4	6.27	217
	360				6.0	6.2	6.2	6.13	248
F *	14	G39C.I	90	60	5.0	5.0	5.0	5.00	655
	28				4.8	4.8	4.8	4.80	948
	60				5.2	5.1	5.2	5.17	462
	240				5.2	5.2	5.2	5.20	644
	360				4.6	4.6	4.6	4.60	560

* Sprayed at Cranfield after a delay.

TABLE II Effect of grit size on reflectivity of blasted surfaces and subsequent pull-off strength of Al coating.

Series	Grit Size	Blasting Conditions		Reflectivity				Pull-off Strength p.s.i.
		Angle°	Pressure p.s.i.	1	2	3	Mean	
I	G39	90	60	4.7	4.8	4.8	4.77	-
		60		4.8	4.9	4.9	4.87	-
		15		5.0	5.1	5.1	5.07	-
	G34	90		4.25	4.25	4.3	4.26	-
		60		4.4	4.4	4.5	4.43	-
		15		4.6	4.6	4.7	4.63	-
	G24	90		4.2	4.2	4.3	4.27	-
		60		4.3	4.3	4.4	4.33	-
		15		4.5	4.5	4.4	4.47	-
	G17	90		4.1	4.1	4.1	4.10	-
		60		4.2	4.2	4.2	4.20	-
		15		4.4	4.4	4.4	4.40	-
II	G39	90	60	4.4	4.6	4.5	4.50	285
		60		5.2	5.1	5.3	5.20	926
		15		5.8	5.7	5.7	5.73	371
	G24	90		5.0	4.8	4.8	4.87	740
		60		5.3	5.2	5.3	5.27	712
		15		5.7	5.8	5.8	5.77	686
	G17	90		4.9	5.0	5.0	4.97	564
		60		5.6	5.6	5.6	5.60	418
		15		5.9	6.0	6.0	5.97	384

TABLE III Influence of colour of light source on reflectivity of blasted surfaces.

Series	Grit	Blasting Conditions			Mean Reflectivity for Different coloured light					Pull-off Strength p.s.i.
		Angle°	Pressure p.s.i.	Time, Secs.	White 1	Red	Blue	Yellow	White 2	
C	G24	90	60	-	5.17	5.13	5.00	5.03	4.87	740
		60		-	5.23	5.20	5.03	5.03	5.27	712
		15		-	5.87	5.97	5.97	6.00	5.77	686
		90		14	5.07	5.13	5.00	5.00	4.77	398
				28	5.07	5.00	4.97	4.93	4.53	968
				60	5.23	5.10	5.13	5.10	4.60	546
				240	5.13	5.07	5.07	5.00	4.90	584
				360	5.17	5.20	5.07	5.03	5.37	620
E	G17	90		-	4.73	4.83	4.97	4.80	4.97	564
		60	-	-	5.33	5.23	5.23	5.33	5.60	418
		15		-	6.20	6.13	6.23	6.23	5.97	384
		90		14	5.70	5.73	5.50	5.70	5.00	688
				28	5.40	5.40	5.47	5.27	5.43	305
				60	5.00	5.10	5.03	5.07	5.53	404
				240	5.77	5.80	5.73	5.87	6.27	217
				360	6.33	6.40	6.30	6.37	6.13	248
G	Derlex	90		-	3.87	4.33	4.27	4.20	3.70	598
		60		-	4.00	4.57	4.60	4.40	3.50	325
		15		-	4.33	4.87	4.90	4.67	3.67	484
		90		14	3.40	4.30	4.20	4.07	3.40	384
				28	3.47	4.27	4.20	4.00	3.47	242
				60	3.27	4.17	4.17	4.00	3.27	387
				240	3.00	3.73	4.10	3.97	3.00	F
				360	3.17	4.20	4.27	4.00	3.17	F

TABLE IV Tests with commercial blasting facilities

Blasting Conditions			Reflectivity				Pull-off Strength p.s.i.
Grit	Angle°	Pressure p.s.i.	1	2	3	Mean	
G24C.I	90	60	4.30	4.30	4.10	4.23	-
			3.90	3.80	3.90	3.87	780
	60		4.40	4.30	4.40	4.37	-
			4.30	4.40	4.40	4.37	655
	15		4.00	3.90	4.00	3.97	-
			4.40	4.50	4.50	4.47	816
	Automatic		4.40	4.50	4.50	4.47	-
			4.30	4.40	4.40	4.37	-
			4.20	4.20	4.30	4.23	526
			4.00	4.10	4.00	4.03	816

TABLE V Comparison of reflectivity registered by an EEL instrument and the Cranfield instrument on grit blasted specimens. (Readings made at the Paint Research Station).

Speci-men No.	Blasting Conditions			P.R.S. Readings							Cranfield Readings		
	Grit	Angle°	Pressure p.s.i.	Longi-tudinal Direc-tion		Trans-verse Direc-tion		Maxi-mum	Mini-mum	Range	1	2	Mean
1	New C.1	15	60	99	98	79	59	>100	58	> 42	8.0	8.0	8.00
2	Blunt	30	60	84	81	85	72	85	72	13	5.4	5.3	5.35
3	New C.1	60	60	78	76	79	66	81	66	15	5.8	5.8	5.80
4	New C.1	30	30	83	82	83	67	85	67	18	5.9	5.9	5.90
5	Blunt	60	30	72	72	65	75	75	65	10	5.0	5.0	5.0
6	Blunt	15	30	91	91	84	67	92	67	25	6.1	6.2	6.15
7	New C.1	60	30	73	72	65	72	74	65	9	5.6	5.6	5.60
8	New C.1	30	60	89	87	64	83	90	63	27	7.0	7.0	7.00
9	Blunt	60	60	68	67	64	68	70	63	7	4.6	4.6	4.60
10	Blunt	15	60	87	86	70	76	87	70	17	5.6	5.7	5.65
11	Blunt	30	30	86	88	88	72	89	71	18	5.6	5.6	5.65
12	New	15	30	91	91	77	61	92	61	31	7.0	7.0	7.00

TABLE VI   Summary of reflectivity tests made at the Paint Research Station.

Specimen No.	Blasting Conditions			Relfectivity				
	Grit	Pressure p.s.i.	Angle°	EEL Instrument				Cranfield Mean
				Maximum	Minimum	Mean	Range	
3	New	60	60	81	66	73	15	5.8
8	"	"	30	90	63	76	27	7.0
1	"	"	15	100	58	79	42	8.0
7	New	30	60	74	65	69	9	5.6
4	"	"	30	85	67	76	18	5.9
12	"	"	15	92	61	76	31	7.0
9	Blunt	60	60	70	63	66	7	4.6
2	"	"	30	85	72	78	13	5.35
10	"	"	15	87	70	78	17	5.65
5	Blunt	30	60	75	65	70	10	5.0
11	"	"	30	89	71	80	18	5.65
6	"	"	15	92	67	79	25	6.15

TABLE VII   Test results for surfaces blasted with non-metallic grits.

Series	Blasting Conditions				Reflectivity				Pull-off Strength p.s.i.
	Grit	Angle°	Time, Seconds	Pressure p.s.i.	1	2	3	Mean	
1	Derlex	90	-	60	3.7	3.7	3.7	3.70	598
		60	-		3.5	3.5	3.5	3.50	325
		15	-		3.6	3.6	3.8	3.67	484
		90	14		3.5	3.3	3.4	3.40	384
			28		3.4	3.5	3.5	3.47	242
			60		3.3	3.2	3.3	3.27	387
			240		3.0	3.0	3.0	3.00	0
			360		3.1	3.2	3.2	3.17	0
2	Silica-Base	Automatic			5.11	4.91	5.01	5.00	484
					5.0	5.1	5.0	5.03	370
	*				4.5	4.5	4.4	4.47	-
	*				4.4	4.6	4.6	4.53	-

* Tests made on commercially blasted specimens immediately after blasting and after standing for 3 hours.

TABLE VIII Variation of strength with time of two adhesives.

Adhesive Adhesive	Time allowed for adhesion before test hours	Pull-off strength p.s.i.								
									Range	Mean
Eastman Kodak 910	½	242	499	370	855	171			171-855	427
	1	995	143	1790	1790	219	1043	1480	143-1790	1066
	2	2380	995						-	1688
	4	3050	3420						-	3235
	16	3700	2870						-	3285
Kelseal 1334	½	0	0	0						
	1	0	0							
	3	0	0							
	5	0	0							
	8	0	0	0	0					
	22	85.5	85.5							
	48	94	101	85.5						

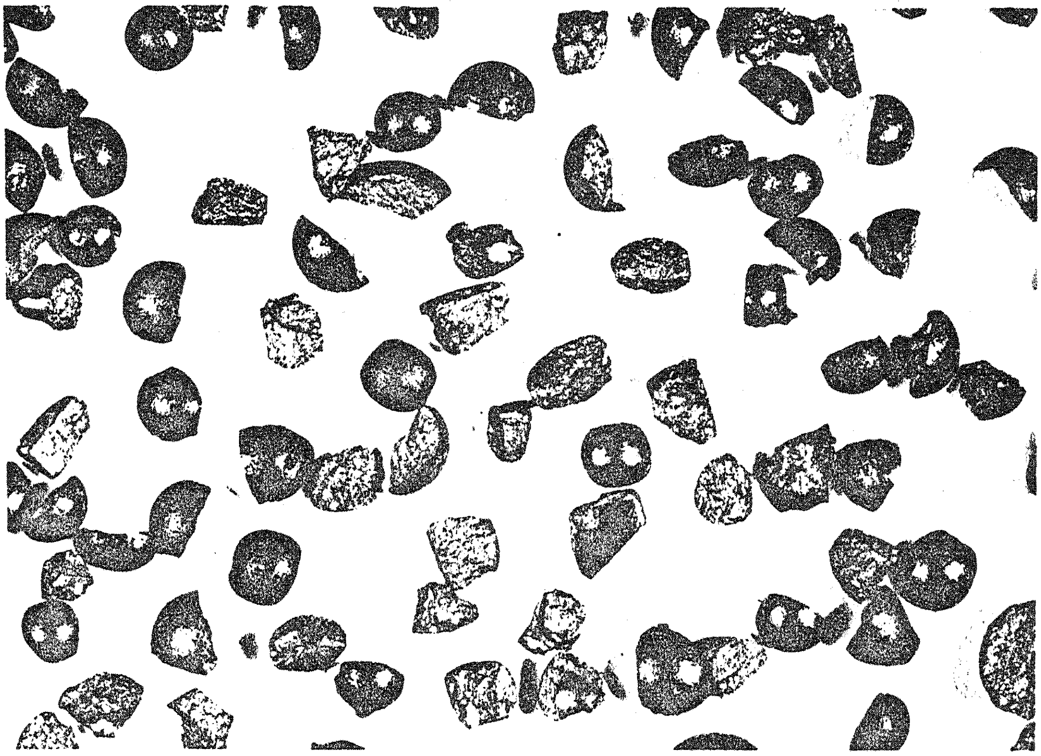

FIG. 1 G39 CHILLED IRON ANGULAR GRIT X5.

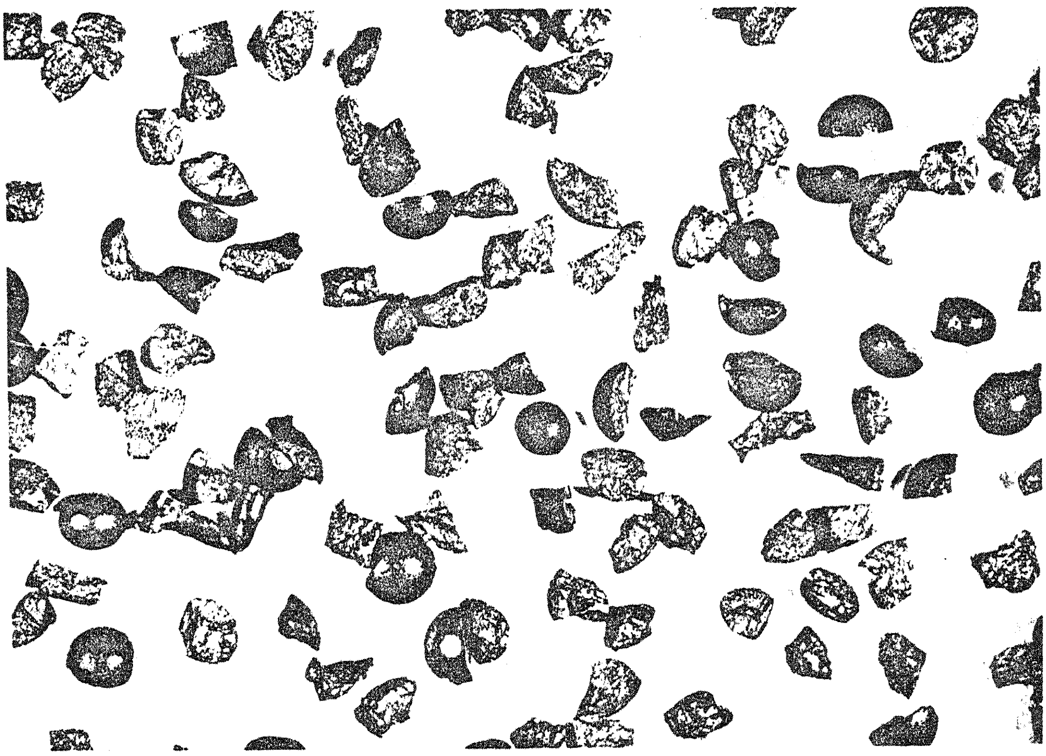

FIG. 2 G34 CHILLED IRON ANGULAR GRIT X5.

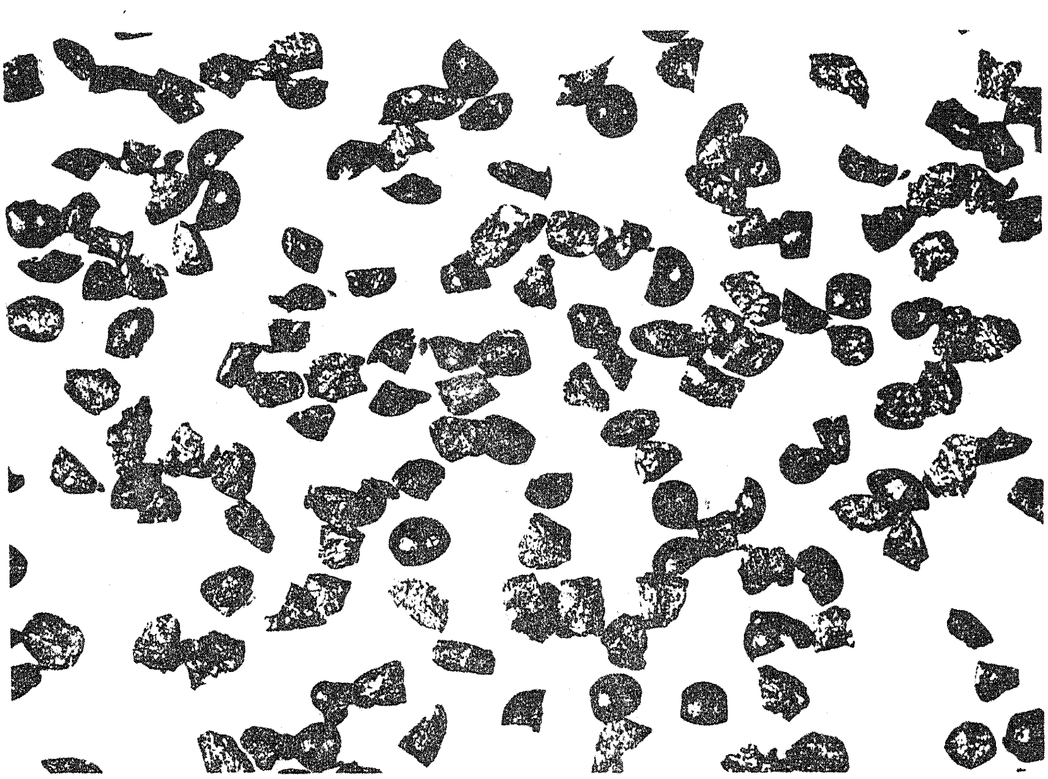

FIG. 3 G24 CHILLED IRON ANGULAR GRIT X5.

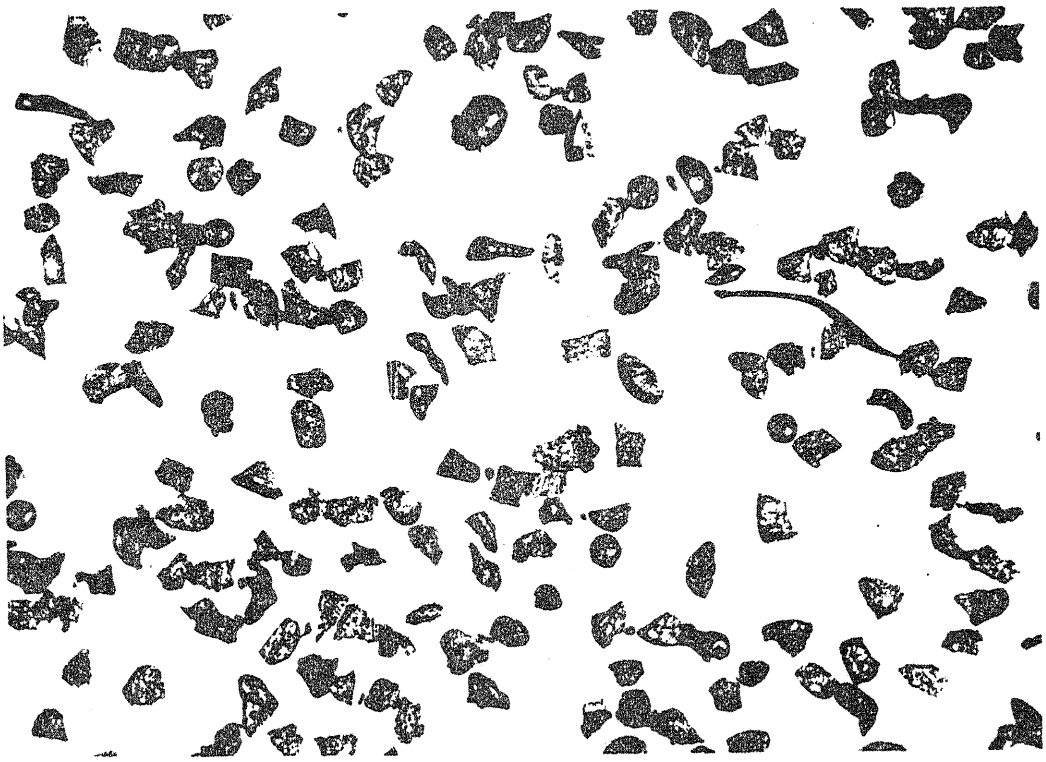

FIG. 4 G17 CHILLED IRON ANGULAR GRIT X5.

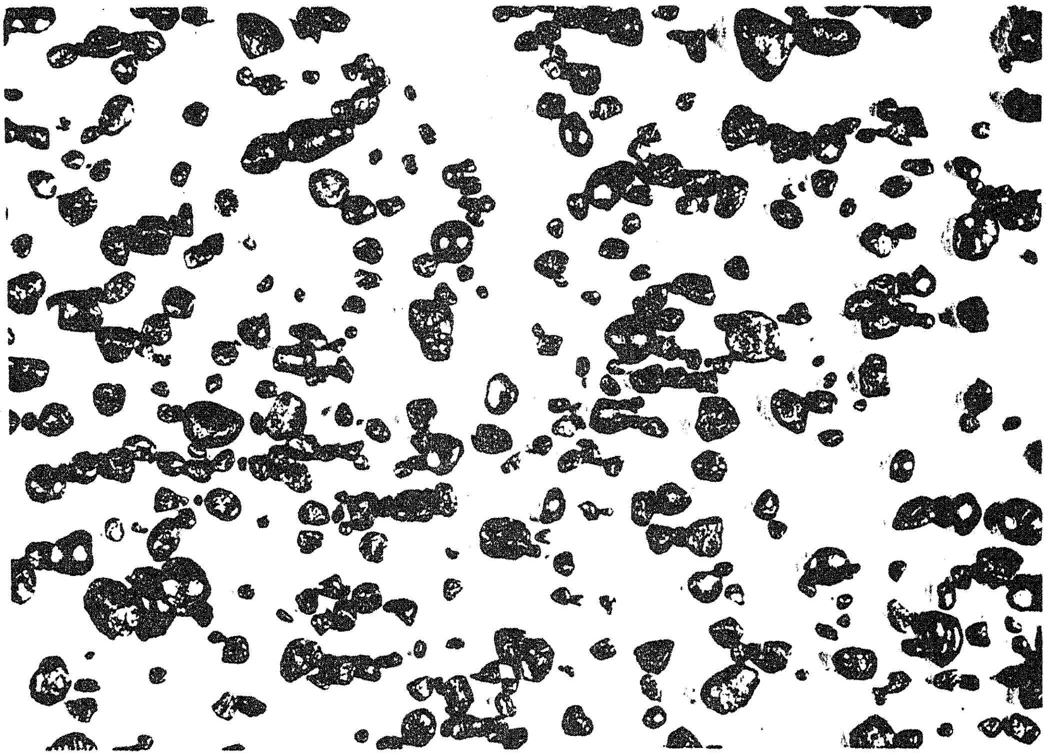

FIG. 5 G24 CHILLED IRON ANGULAR GRIT AS USED IN A COMMERCIAL BLASTING CABINET X5.

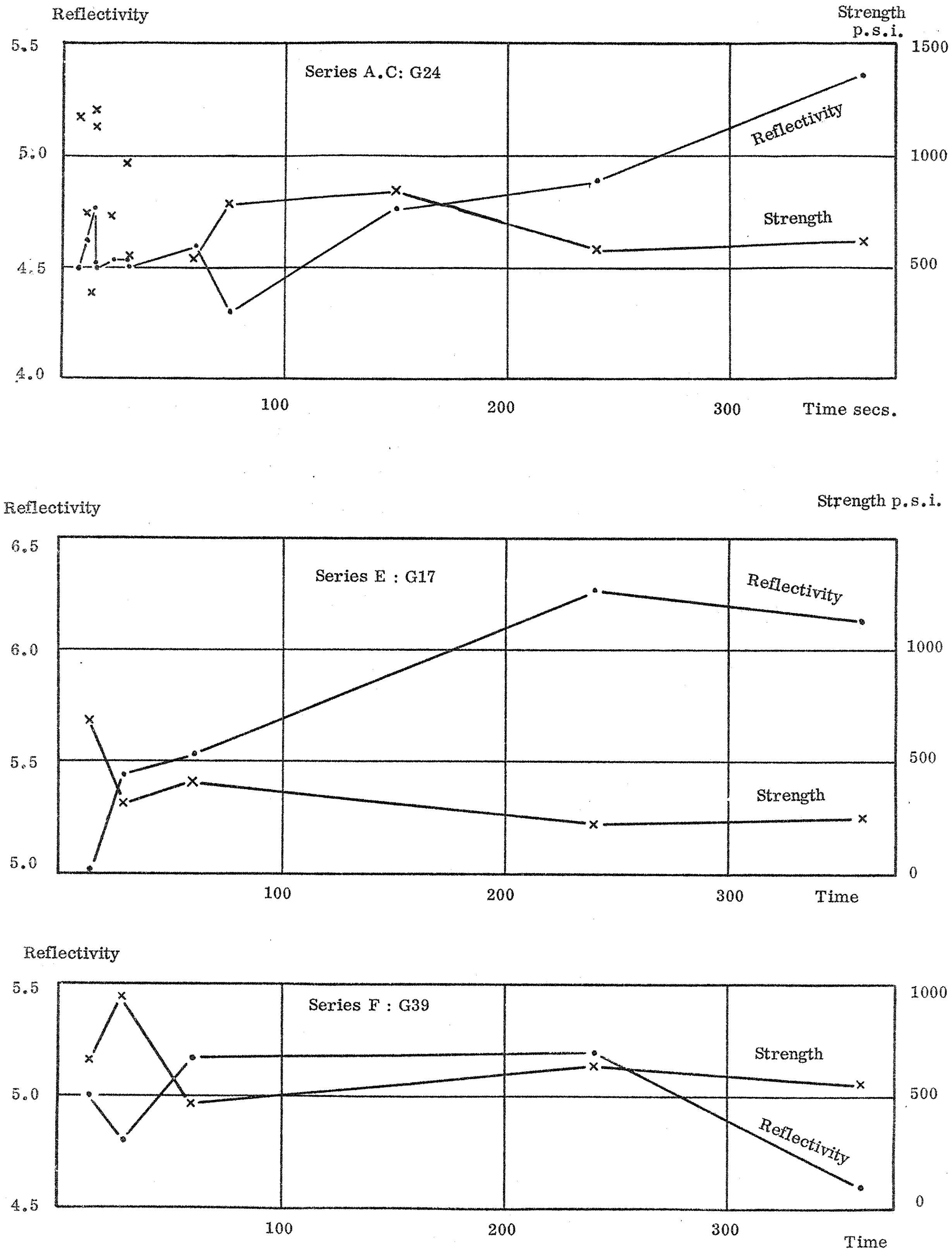

FIG. 6 EFFECT OF BLASTING TIME ON REFLECTIVITY AND PULL-OFF STRENGTH FOR G24, G17 AND G39 GRIT.

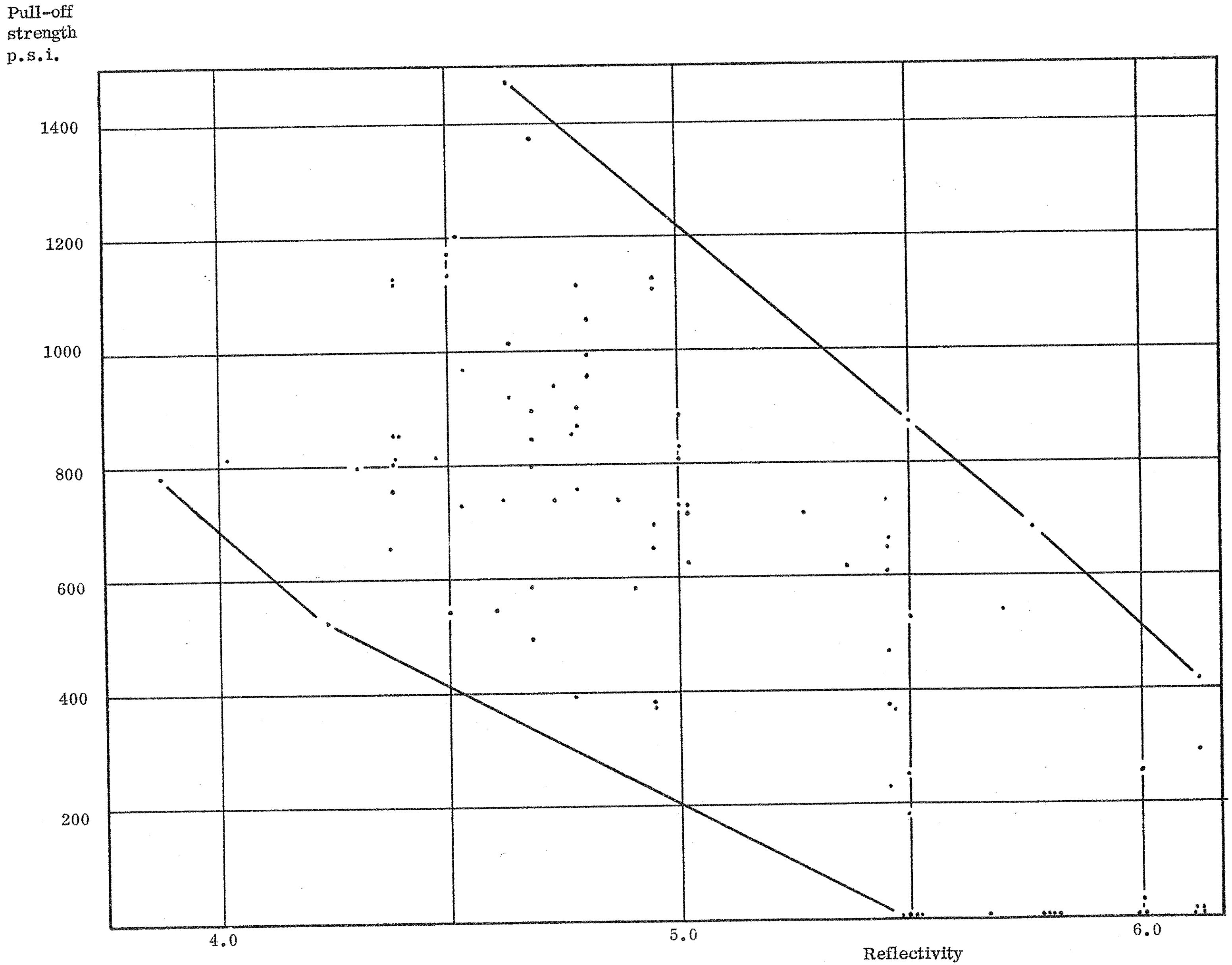

FIG. 7 RELATIONSHIP BETWEEN REFLECTIVITY AND PULL-OFF STRENGTH FOR G24 GRIT.