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EFFECT OF RATE OF LOADING ON SHEAR STRENGTH OF ADHESIVE-BONDED LAP JOINTS

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FOREWORD

This report was prepared by the Metals Branch and was initiated under Project No. 7360, Materials Analysis and Evaluation Techniques, Task No. 73605, Design Data for Metals, formerly RDO No. 614-13, and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. R. E. Wittman acting as project engineer.

Since the completion of this report a new aluminum alloy designation system has been established by the Aluminum Association. Consequently, 24S-T3 mentioned in this report is now 2024-T3.

The original data for this work are recorded in "United States Air Force Engineering Project Record Book No. 2810".

ABSTRACT

The effect of various rates of loading on the shear strengths of several metal to metal adhesives is presented. The loading rate ranged up to values as high as 10^8 psi per minute.

The shear strength for the more rigid adhesive types, vinyl-phenolic and epoxide, remained fairly constant at the increased rates of loading.

The shear strength of the less rigid types of adhesives, nitrile rubber-phenolic and nylon-neoprene rubber-phenolic, increased appreciably with increases in loading rate and at the highest rate (0.002 second to failure) the strengths were more than doubled, the maximum increase being about 230 percent.

Strengthwise, the more rigid adhesives had higher values when stressed statically (600-700 psi per minute) than did the less rigid types. As a group, these values averaged 4110 psi and 2960 psi respectively.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

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Technical Director
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A. INTRODUCTION

The purpose of this investigation was to determine the effects of rate of loading at room temperature on the shear strength of adhesive bonded lap joints. Static tests were conducted in accordance with USAF Specification No. 14164 (now superseded by MIL-A-8331). The various nominal rates of loading were: static (approximately 4 - 6 minutes) and 1.0 second, 0.2 second, 0.02 second, and 0.002 seconds to fracture.

B. MATERIALS

Eight adhesives representing four general chemical types were used in the program. The four types were: epoxide, vinyl-phenolic, nitrile-rubber phenolic and phenolic-nylon-neoprene rubber. Commercial identifications and descriptions of the individual adhesives are as follows:

a. Plycozite 117-C, U.S. Plywood Corp.
vinyl-phenolic; liquid, 1 part.

b. Plastilock 604, B.F. Goodrich Co.
nitrile rubber-phenolic; unsupported film.

c. Plastilock 601, B.F. Goodrich Co.
Nitrile rubber-phenolic; unsupported film.

d. Epon VI, Shell Chemical Co.
epoxide; liquid, 2 part.

e. Scotchweld AF15, Minnesota Mining and Mfg. Co.
nitrile-rubber-phenolic; unsupported film.

f. PA101, Bloomingdale Rubber Co.
nitrile-rubber-phenolic; liquid, 2 part.

g. Metlbond MN3C, Narmco Inc.
phenolic-nylon-neoprene rubber primer; nylon fabric tape impregnated with phenolic nylon-neoprene rubber.

h. FM-47 Bloomingdale Rubber Co.
vinyl-phenolic liquid, 1 part.

C. TEST SPECIMENS

Lap joint shear specimens were as shown in Figure 1. The bonded area was a one-half inch lap joint a half inch wide. Specimens were machined from 0.064 inch 24S-T3 clad aluminum alloy sheet. Five specimens were made from each 6 inch panel bonded, two of which were tested under static conditions and the remaining three at one specific increased rate of loading. A total of four panels of each adhesive were used.

D. PROCEDURE

Tests were conducted in several different machines. A Tinius Olsen 2,000 lb. capacity Universal Testing Machine was used to determine the strength under static conditions. For tests of 1.0 second duration, a Baldwin-Southwark 60,000 lb. Universal Testing Machine was employed and by using the head motor in conjunction with the hydraulic loading system of this machine, tests to ultimate shear strengths were possible in 0.2 second. A General Motors fatigue machine adapted for rapid loading allowed tests in 0.02 second. For tests in the vicinity of 0.002 second, a Tinius Olsen combination impact testing machine with a special jig for tensile loading, and rubber shock absorbers was used.

Stress under static conditions was recorded directly from the indicator dial of the testing machine. For all other rates of loading the dynamometer shown in Figure 2 was placed in series with the specimen to indicate the stress by means of strain-measurement. The dynamometer consisted of 75S-T6 sheet Aluminum Alloy machined to the form of a tensile specimen which was riveted at each end to aluminum alloy connecting blocks. The cross section was such that the maximum strain when the necessary load was applied did not exceed the elastic limit of the 75S-T6 alloy.

The electrical recording system consisted primarily of a conventional Wheatstone bridge. Each arm of the bridge contained two A-17-2 Baldwin-Southwark electrical resistance strain-gages. The gages of arm 1 were glued side by side to one face of the dynamometer, in the center of the gage section, and the gages of arm 3 were glued similarly to the opposite face. The remaining gages in arms 2 and 4 were glued to a piece of 1/16 inch sheet aluminum alloy for stability. In addition to the gages, each bridge contained a balancing resistance, a calibrating resistance and a switch to introduce the calibrating resistance. The bridge was powered by a 45 volt battery and the unbalance of the bridge was passed to a Dumont Type 304-H cathode ray oscilloscope.

The signal from the load indicating bridge was impressed on the vertical deflection plates of the oscilloscope. As a means of determining the test duration, a necessary sweep was set into the oscilloscope at a known frequency, using a Hewett Packard Audio Oscillator. The frequencies used were 10, 10, 100 and 500 cps for the 1.0, 0.2, 0.02 and 0.002 second rates, respectively. The traces provided by the oscilloscope were photographed using a Dumont Recording Camera attachment. Figure 3 shows a photograph of the film record of the test in which each horizontal sweep is 0.1 second. As indicated in the figure, "C" is the point at which failure occurred.

The calibration of the bridge was accomplished in the following manner. The dynamometer was placed in the Tinius Olsen Machine by means of yolks and pins. With the bridge balanced and the equipment ready for operation the calibrating resistance was switched into the arm of the bridge, providing an unbalance and causing the sweep to trace a horizontal path across the face of the tube. This deflection was photographed. With the calibrating resistance out of the circuit, a series of fixed loads were applied to the dynamometer and the displacement of the sweep, due to strain, photographed for each load. From the positive print, the ratios of the displacements to the corresponding loads were calculated and averaged to give a value in lbs. for the calibrating resistance.

The sequence of operations for a test is as follows: the specimen and dynamometer are connected in series and by means of yolks, the assembly is inserted into one of the testing machines.

The frequency of the oscilloscope is set using the oscillator. A photograph of the tube is taken showing the deflection caused by the calibrating resistance being put into the circuit. With the calibrating resistance out of the circuit, the camera shutter is opened and the load is applied to the specimen. After failure, the shutter is closed. After developing, the film, a measurement of the maximum deflection of the trace during the loading cycle and of the calibration deflection is made. By means of a ratio, the load in lbs. at which failure occurred is calculated.

E. RESULTS AND DISCUSSION

The results of tests for the individual panels with percentage increase or decrease in strength with loading time are given in Table I. The stress shown for each panel is an average of two specimens for static loading conditions and of three specimens for rapid loading conditions. Under static conditions (600-700 psi/min) the strongest adhesive was plycozite, having an average shear strength of 4240 psi.

Plycozite and FM47, both of which are vinyl-phenolic adhesives, showed the least change in shear strength at the increased rates of loading. The shear strength of the one epoxide tested (Epon VI) remained fairly constant at all rates with the exception of the 0.002 second rate which gave values approximately 25 percent higher than the static load.

The above adhesives are relatively rigid, hard types.

Strengthwise, these types had higher values when stressed slowly than did the less rigid type adhesives. The vinyl-phenolic adhesives averaged over 4200 psi under normal static loading, and the epoxide adhesive above 3900 psi.

Within the nitrile rubber-phenolic group, four adhesives were evaluated. As the rate of loading was increased, the shear strengths also increased. At a speed of 0.002 second, the strengths had more than doubled, without exception. The percentage increase was greatest for Scotchweld AF15 adhesive, being 232 percent above or more than triple the static value. This adhesive also had the greatest percentage increase for each of the other speeds tested. The remainder of this group, Plastilock 601, Plastilock 604, and PA 101 showed an increase in shear strength averaging from 130 to 170 percent. The normal loading static shear strength of this group averaged approximately 22 percent lower than for the vinyl-phenolic and epoxide adhesives, but approximately 91 percent higher than these rigid adhesives at a speed of 0.002 second to the ultimate.

Data were obtained on one phenolic nylon neoprene rubber base adhesive, this being MN3C on nylon fabric tape. The normal static shear strength values averaged approximately 2400 psi, and at faster shearing speeds the strength increased a maximum of 113 percent.

The averaged shear strength of PA 101, nitrile-rubber phenolic adhesive, at 0.002 second, of 8820 psi exceeded all others although the other nitrile-rubber-phenolic adhesives gave values close to 8000 psi. The more rigid adhesives had values averaging 5000 psi and below at this speed.

Figures 4 and 5 respectively, show the effects of loading rate on the rigid and relatively less rigid adhesive groups. In these figures the fracture stress is plotted against the logarithm of the loading rate in psi per minute. Taking into account the normal scatter which is encountered in these tests the plot for the more rigid adhesives, Figure 4, gives a horizontal straight line through a stress of about 4200 psi. This shows that rigid adhesives are basically unaffected by increased rates of loading.

The less rigid adhesives plotted in Figure 5 give a reasonably straight line of increasing stress between the static and 1.6×10^6 psi/min loading rate (0.02 second to ultimate). MN3C, while showing the same trend as the other less rigid adhesives, developed significantly lower properties throughout the loading rate range. The shear strengths at the maximum rate investigated were such that the curve assumes a greater slope at the higher loading rates. This may be attributed to insufficient tests but it is believed that the data obtained were conclusive enough to show the general characteristics of these adhesives. This overall curve is significant because it is in keeping with the expected behavior of more elastic materials.

All joints were carefully examined after failure and it was found that, except for FM-47, shear in all cases was from 90 to 100 percent cohesive (failure within the adhesive rather than peel from the metal). For FM-47, failure was 100 percent adhesive (peel). This was true for all rates of loading.

TABLE I
SHEAR STRENGTH IN PSI OF INDIVIDUAL ADHESIVE PANELS

Adhesive Trade Name and Chemical Type	Panel No.	Static Load psi*	Rapid Loading seconds to failure	Rapid Loading psi** to failure	Loading Rate At Failure x 10^6 psi/min	Percent Increase in Strength
		Harder, More Rigid Types				
Plycozite 117C	A	4080	1.0	4320	0.26	+ 6
	B	4300	0.2	4820	1.45	+ 12
(Vinyl Phenolic)	C	4320	0.02	4400	13.20	+ 2
------	D	4280	0.002	4060	121.80	- 5
FM47	AN-1	4640	1.0	4540	0.27	- 2
	AN-2	4640	0.2	4500	1.35	- 2
(Vinyl Phenolic)	AO-1	3760	0.02	3720	11.16	- 1
-------	AO-2	3760	0.002	3780	113.40	0
Epon V1	Q	4000	1.0	4140	0.25	+ 4
	R	4200	0.2	4240	1.27	+ 1
(Epoxide)	S	3600	0.02	3560	10.68	- 1
	W	3880	0.002	5000	150.00	+ 29
		Softer, Less Rigid Types				
Plastilock 604	E	2880	1.0	4360	0.26	+ 51
	F	3200	0.2	5120	1.54	+ 60
(Nitrile Rubber-Phenolic)	G	3260	0.02	5320	15.96	+ 63
--------	H	2900	0.002	7880	236.40	+ 172
Plastilock 601	I	2320	1.0	3580	0.21	+ 54
	J	3620	0.2	4920	1.48	+ 36
(Nitrile Rubber Phenolic)	M	3660	0.02	5320	15.96	+ 46
-------	O	3120	0.002	8160	244.80	+ 162

TABLE I, cont'd
SHEAR STRENGTH IN PSI OF INDIVIDUAL ADHESIVE PANELS

Adhesive Trade Name and Chemical Type	Panel No.	Static Load psi*	Rapid Loading seconds to failure	Rapid Loading psi** to failure	Loading Rates At Failure x 10^6 psi/min	Percent Increase in Strength
		Softer, Less Rigid Types				
Scotchweld	AC	2520	1.0	4320	0.26	+ 71
	Z	3040	0.2	5680	1.70	+ 87
(Nitrile Rubber Phenolic)	AA	2440	0.02	5080	15.24	+ 108
------	AB	2360	0.002	7840	235.20	+ 232
PA 101	AR	3000	1.0	4200	0.25	+ 40
	AF	3740	0.2	4920	1.48	+ 32
(Nitrile Rubber Phenolic)	AJ	4240	0.02	5800	17.40	+ 37
------	AL	3880	0.002	8820	264.60	+ 127
Metlbond MN3C	AM-1	2420	1.0	3140	0.19	+ 30
	AM-2	2420	0.2	3400	1.02	+ 40
(Phenolic Nylon-Neoprene Rubber)	AM-3	2420	0.02	3000	9.00	+ 24
------	AM-4	2420	0.002	5160	154.80	+ 113

* Average of two test results.
** Average of three test results.

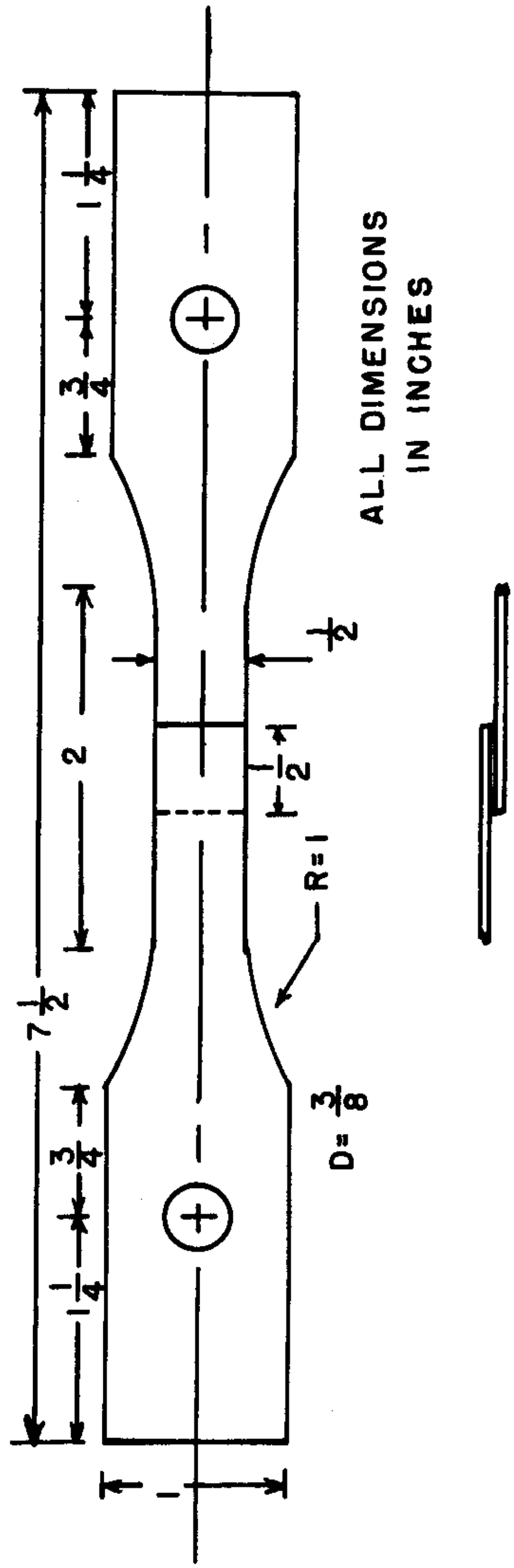

FIGURE I. METAL TO METAL ADHESIVE SPECIMEN

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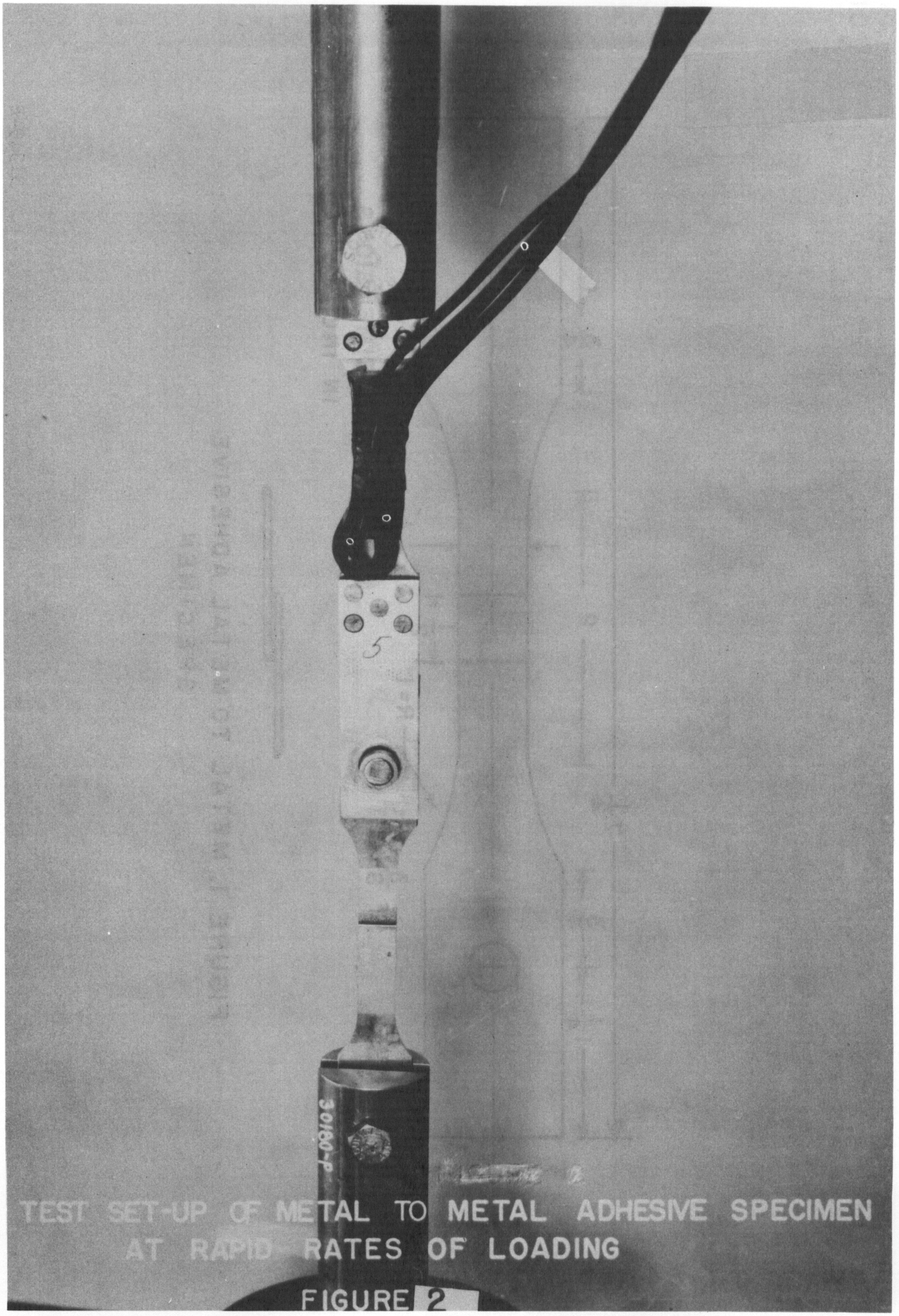
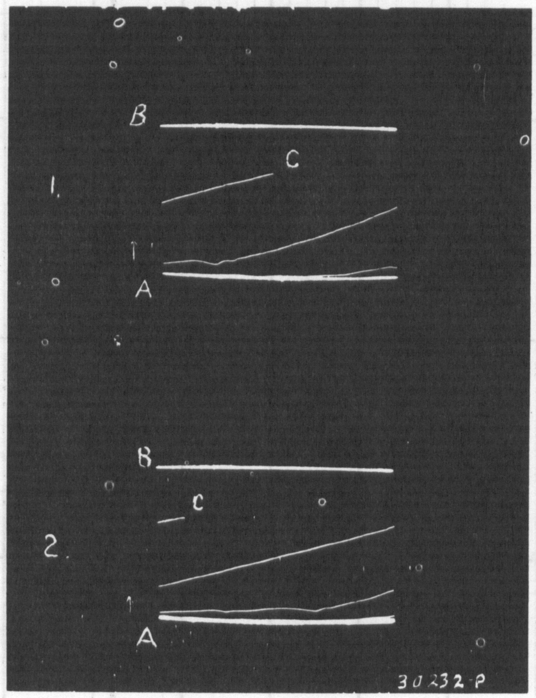


TEST SET-UP OF METAL TO METAL ADHESIVE SPECIMEN
AT RAPID RATES OF LOADING

FIGURE 2

FIGURE 3

Oscilloscope Film Record of Tensile Tests on FM47 Adhesive



A-B = Calibrating Deflection = 1640 lbs.
Spec. 1. A-C - Tensile Load = 1130 lbs. = 4520 psi
Spec. 2. A-C - " " = 1100 lbs. = 4400 psi
Recurring Sweep set at 10 cps - Panel-AN-2

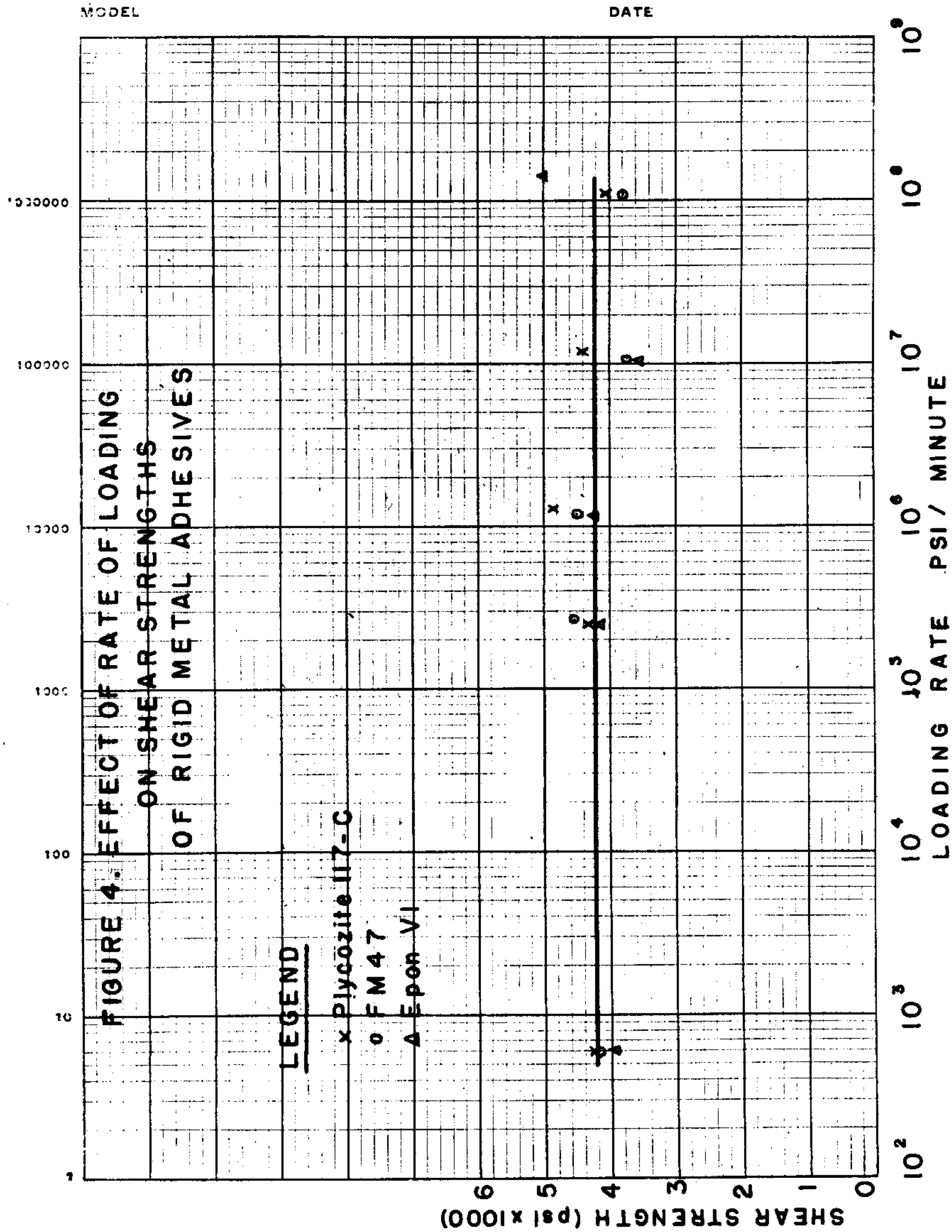


FIGURE 4. EFFECT OF RATE OF LOADING ON SHEAR STRENGTHS OF RIGID METAL ADHESIVES

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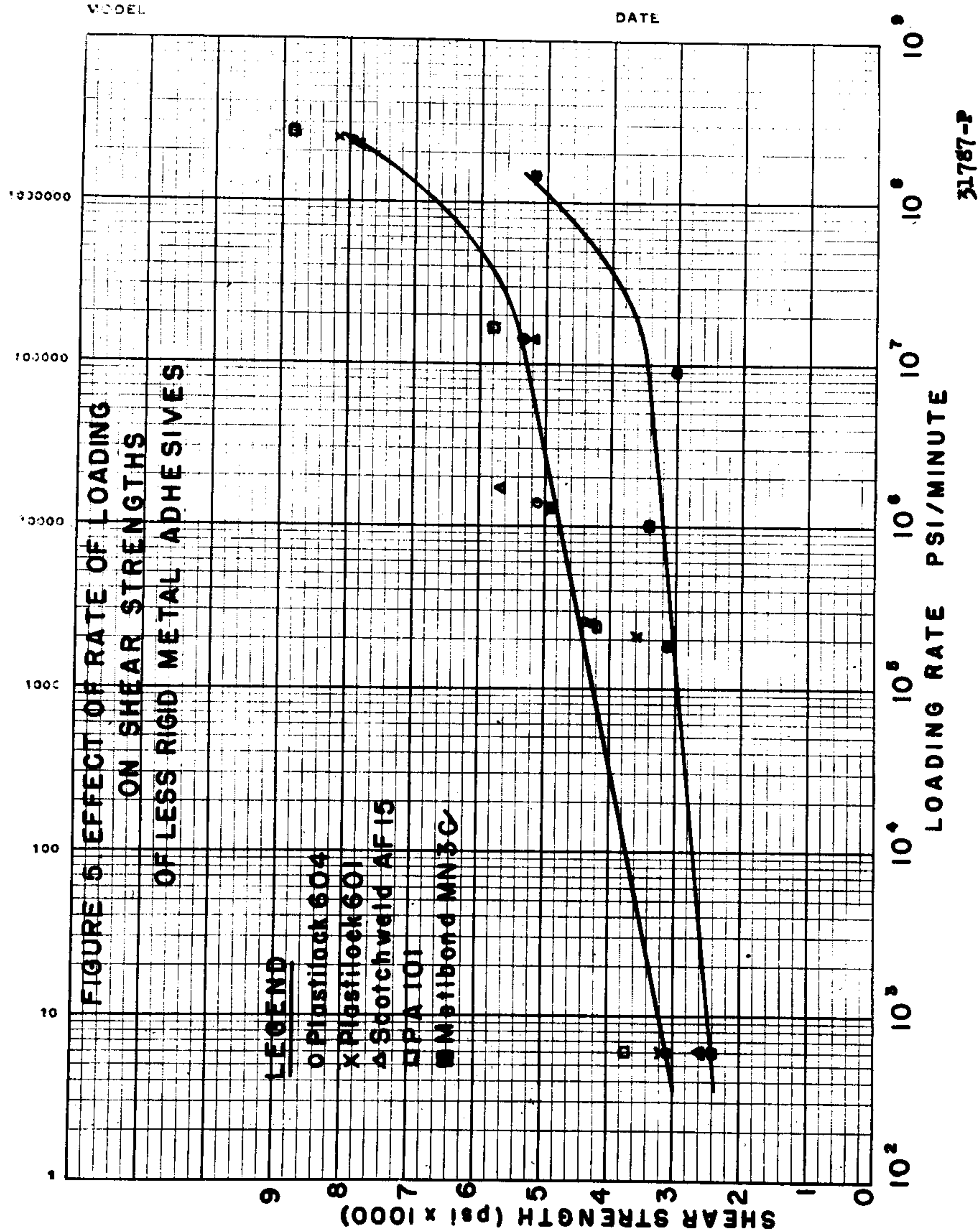

FIGURE 5 EFFECT OF RATE OF LOADING ON SHEAR STRENGTHS OF LESS RIGID METAL ADHESIVES