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CORRELATION DETERMINATIONS BETWEEN STRESS CORROSION CHARACTERISTICS OF WROUGHT 7039 ALUMINUM ARMOR AND OTHER ALLOY CHARACTERISTICS - BALLISTIC PERFORMANCE, YIELD STRENGTH, AND ELECTRICAL CONDUCTIVITY

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Frankford Arsenal
Philadelphia, Pennsylvania

April 1975

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This study was performed to determine whether a correlation could be established between the stress corrosion resistance of wrought 7039-T6 aluminum armor plates and other alloy characteristics such as ballistic performance, yield strength, and electrical conductivity. A survey and statistical analysis were conducted on acceptance test data available for about 500 preproduction lots of 7039-T6 plates.

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20 Abstract (cont'd)

In addition, 7039 aluminum plates were heat treated to provide several selected strength levels outside the MIL-A-46063 specification range to determine whether a correlation could be found over a wider range of properties than that covered by the specification.

The results of the work indicate that:

1. No linear correlation could be found between the SCC resistance of 7039-T6 alloy plates and other characteristics i.e. yield strength, ballistic performance, and electrical conductivity.

2. No significant distinction could be made between the yield strength or ballistic performance of 7039-T6 material that passed the standard SCC test and the corresponding property of material that failed the test.

Recommendations are given for future work on other weldable aluminum alloys in which correlations might possibly exist.

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INTRODUCTION

The work described in this report was performed under Army Project AH91, "Tank and Automotive Technology". The purpose of the work was to determine whether a correlation could be established between stress corrosion resistance of 7039-T6 aluminum armor plates and other characteristics such as ballistic performance, yield strength, and electrical conductivity. The work was directed toward overcoming problems associated with present acceptance criteria for 7039 armor material.

In most instances, 7039-T6 aluminum armor plate is accepted from producers on the basis of several acceptance tests (MIL-A-46063) which include ballistic performance, tensile properties, and stress corrosion cracking (SCC) resistance. However, because of the length of time required for the SCC test, it was desirable to determine whether SCC characteristics could be related to other parameters such as ballistic performance, yield strength, and electrical conductivity. If such a correlation could be found, a faster test for assuring the required SCC resistance would be available.

METHODS AND PROCEDURES

This program was divided into two phases. The first phase involved a survey and statistical analysis of acceptance test data obtained from preproduction lots of 7039-T6 armor plates.

Specifically, the statistical analysis was carried out to determine whether yield strength or ballistic performance data for 7039 material could be correlated with SCC acceptance test data[1] and/or if yield strength and ballistic performance data corresponding to plates which failed the SCC test could be distinguished from comparable data obtained for plates which passed the SCC test.

The second phase was concerned with measuring the ballistic performance, SCC resistance, and electrical conductivity of 7039 armor plates which were heat treated to provide several selected conditions of strength, all of which exceeded the minimum specified 51 ksi yield strength.

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[1]MIL-A-46063 - Five of nine C-ring specimens stressed to 35 ksi in the short transverse direction shall not exhibit cracking after four days when tested by the standard 3.5% NaCl Alternate Immersion (A.I.) Test.

Phase I - Statistical Analysis

Data for the statistical evaluation were compiled from acceptance tests on about 500 different preproduction lots of 7039-T6 aluminum armor plates manufactured from 1965 to 1974 by four suppliers. Several plate thicknesses, from 0.75 inch to 2.25 inches, were included in the compilation. The data correlated included yield strength (Y.S.), protection ballistic limits (PBL) against selected small arms projectiles and SCC characteristics. Protection ballistic limit values of aluminum armor are directly related to the thickness of the plates. Therefore, in order to eliminate the thickness variable from the ballistic correlation computations, all PBL values were converted to weight merit ratings (WMR) and velocity merit ratings (VMR). These merit ratings were based on the ballistic properties of rolled homogeneous (RH) steel armor (MIL-S-12560) and standard 7039-T6 aluminum armor (MIL-A-46063). The stress corrosion data were recorded as the number of specimens (out of 9 being tested) that failed during a 4 day test period.

The projectile-plate interactions that occurred for the armor piercing (AP) projectile penetrations were significantly different from those that occurred for fragment simulator (FS) projectile penetrations. Therefore, each ballistic test was considered on its own merit. Hence, the ballistic acceptance test data were divided into four groups, each based on the projectile used in the evaluation. These projectile groups consisted of 20mm fragment simulator (FS), caliber .50FS, caliber .50 APM2, and caliber .30 APM2.

Three techniques were utilized for the statistical analysis of the data obtained for each ballistic group, and the formula used for each of the calculations is given in Appendix A. The three techniques are described below.

Correlation Coefficient (r)

The correlation coefficient is a measure of the degree of association found between two parameters in a series of observations. In this study the correlation was assumed to be linear since higher order functions would not be expected based on metallurgical principles. In a linear correlation, the values of the coefficient range between 0 (indicating complete independence between the two parameters) and $\pm$ 1 (indicating complete dependence between the two parameters). For each projectile test group, the correlation coefficient (r) was determined between the number of SCC failures (0 through 9) and the ballistic and mechanical properties. For this study, coefficients in excess of $\pm$ 0.90 were considered indicative of a correlation.

F Test

The F test is used to determine whether a significant difference exists in the average values of a particular parameter for several different categories or conditions. The F test involves calculating an F value for a given parameter in each of several categories and comparing the calculated F value with the tabulated critical F value for a given confidence level. If the calculated value is equal to or greater than the critical value, then a significant difference is indicated between the categories of that parameter for the selected confidence level.

In this study, the selected confidence level was 0.99 and the test was used to establish whether the ballistic and mechanical properties of those plates which had a given number of SCC failures could be distinguished from the ballistic and mechanical properties of plates having a different number of SCC failures.

Student t Test

This test is similar to the F test in that it can make distinctions between the averages of populations; however, it does this for only two categories. As in the case of the F test, the t test involves comparing a calculated value with a critical range of values which are obtained from standard tables. The calculated values must be numerically greater than the tabulated values in order to show a significant difference. The t test was used in this experiment to determine whether a distinction could be made between the average values of ballistic and mechanical properties of armor plates that had passed the SCC test (0 to 4 failures) and the corresponding average property values of plates that had failed the SCC test (5 or greater failures). As in the F test, a confidence level of 0.99 was used.

Phase II - Materials Evaluation

Materials Preparation

The major portion of the experimental work was performed on 7039 armor plate (lot #485151) which was supplied for this study in the T6 temper by the Tank Automotive Command (TACOM). The plates, as received, were 36 inches x 36 inches x 1-1/4 inches and were subsequently cut into smaller plates, 12 inches x 18 inches, in order to provide sufficient material to be tested in the T6 temper and in other selected tempers. The tempers were chosen so as to provide a range of strengths which would include the minimum specified strength (51 ksi yield) as well as relatively high strengths. The thermal treatments consisted of a solution heat treatment for 3 hours at 855° F, cold water quench and a 4 day natural aging treatment, followed by selected artificial aging treatments. The aging treatments were:

Temper 1 - Heat 16 hours at 175°F
- Raise temperature 25°F per hour to 240°F
- Heat 48 hours at 240°F

Temper 2 - Heat 24 hours at 250°F

Temper 3 - Heat 16 hours at 300°F

Tests were also performed on two lots of 7039-T64 plates, 1¼ inch thick, produced by the Kaiser Aluminum & Chemical Corp. These plates had previously passed the standard acceptance test.

Test Procedures

All of the mechanical property, stress corrosion and ballistic evaluations were conducted in accordance with the 7039-T6 aluminum armor specification (MIL-A-46063) and electrical conductivity measurements were taken in accordance with accepted test procedures.

Mechanical Property Tests

Tensile properties were determined from standard round 0.505 inch diameter tensile bars taken in the long transverse direction from the mid-plane of the various 7039-T6 test plates. Two specimens were evaluated for each condition.

Stress Corrosion Tests

The standard 3.5% NaCl A.I. stress corrosion test was performed using C-ring specimens stressed to 35 ksi in the short transverse direction. The area of the C-ring exposed corresponded to the mid-plane of the plate.

Ballistic Tests

Ballistic tests were conducted at 0° impact obliquity using caliber .30 APM2, caliber .50 APM2, caliber .50FS and 20mm FS projectiles. The protection ballistic limits (PBL) were based on the average of the three highest partial and three lowest complete penetration velocities falling within a range of 150 feet per second. Merit ratings[2] based on ballistic properties of rolled homogeneous steel armor (MIL-S-12560) and 7039-T6 aluminum armor (MIL-A-46063) were determined as follows:

$$\text{Velocity Merit Ratings (VMR)} = \frac{PBL_x}{PBL_s}$$

where PBL_x is the protection ballistic limit of experimental 7039-T6X

[2] Mascianica, F. S., "Ballistic Technology of Lightweight Armor" (U), AMMRC TR 73-47, Nov. 1973 (CONFIDENTIAL).

material tested in this study, and PBL_s is the protection ballistic limit of MIL-S-12560 steel or MIL-A-46063 aluminum at an areal density equal to that of the experimental armor.

$$\text{Weight Merit Rating (WMR)} = \frac{AD_s}{AD_x} \times 100$$

where AD_x is the areal density of the experimental 7039-T6X armor, and AD_s is the areal density of MIL-S-12560 steel or MIL-A-46063 aluminum at a protection ballistic limit velocity equal to that of the experimental armor.

Electrical Conductivity Tests

Electrical conductivity measurements were made using a Forster Sigmatest Meter which utilizes the principle of eddy currents and provides values in terms of percent of the International Annealed Copper Standard (% IACS).

RESULTS AND DISCUSSION

Phase I - Statistical Analysis

Correlation Coefficient (r)

The results of the correlation coefficient analysis are presented graphically in Figures 1 to 5; the graphs also list the calculated correlation coefficient, r, for each data group evaluated. Four data groups were plotted on each figure; they correspond to the four projectile groups, 20mm FS, Caliber .50FS, Caliber .50 APM2 and Caliber .30 APM2, obtained from the 7039-T6 acceptance test data. The plots in Figure 1 show comparisons of mean yield strengths, with their ranges indicated, for ten SCC categories (0 to 9 failures). These data show that no degree of correlation existed between yield strength and the number of SCC failures. The extremely low calculated r values substantiate the graphical presentation. Figures 2 and 3 compare mean weight merit ratings, calculated against RH steel and 7039 aluminum, respectively, for the ten SCC failure categories. Similar plots are shown in Figures 4 and 5 for mean velocity merit rating data. In all cases, no correlation could be found between the merit rating values of 7039-T6 armor and the number of SCC failures.

F Test

The results of the F test are listed in Tables 1 to 5. Each Table is divided into four different projectile groups. The data within the tables include the mean values of the test plate characteristic (yield strength, VMR, or WMR), the standard deviations, as well as the sample sizes for each of the ten SCC failure categories. The calculated and critical F ratios, are also listed in the tables. It can be seen that none of the calculated F ratios exceed the critical F ratios, and therefore no significant difference could be made between the mean values of a characteristic parameter in each of the 10 different SCC categories.

Student t Test

The results of the Student t test are presented in Tables 6 through 8. For the various characteristic parameters and projectile groups, it can be seen that none of the calculated t values fell outside their critical boundary regions. Thus, no distinction could be made between the mean values of properties of those specimens that passed the SCC test (0 - 4 failures) and those that did not pass (5 - 9 failures). It should be pointed out that, based on the results of the F tests, if the Student t test used a different number of failed specimens (other than 4) as the pass-fail criteria, this result would not change.

Phase II - Materials Evaluation

The results of all tests are shown in Table 9. The tensile results from tests on plates received from TACOM and from Kaiser show that acceptable strengths were achieved in all tests; the yield strength varied from 51.2 ksi to 59.5 ksi. The ballistic results show that all plate material had acceptable ballistic limits against FS and AP projectiles, although it appears that the lowest strength material (aged at 300°F) had slightly inferior ballistic limits. It should be noted that this material did not pass the SCC test. Note also that the conductivity of the material aged at 300°F was significantly higher than the material aged at 250°F or of the material given the two step aging treatment of 175°F + 240°F. Tests on the two lots of Kaiser material showed that the strength and ballistic properties were similar, although the conductivities were significantly different. Both lots passed the SCC tests.

The data in Table 9 show that on comparing ballistic performance with strength, it appears that ballistic limit was essentially unaffected by variations in strength (51 to about 60 ksi yield). The fact that the specimen aged at 300°F did not pass the SCC test was unexpected since this material had the lowest strength and the highest conductivity, both of which usually promote improvements in SCC resistance of other 7000 series alloys. Thus, based on the results of these tests, it is difficult to establish a correlation between SCC and other properties such as yield strength, ballistic performance, and electrical conductivity of 7039 aluminum armor plate. It is believed that this difficulty results, in part, from the fact that any variation in strength which might exist in commercially produced 7039-T6 material is too small to produce significant differences in properties such as ballistic protection or SCC resistance.

CONCLUSIONS

1. The statistical analysis of data obtained for 500 preproduction test plates showed that:

   a. No linear correlation could be found between the SCC resistance of 7039-T6 alloy plates and other alloy characteristics such as yield strength and ballistic performance.

   b. No significant distinction could be made between the yield strength or ballistic performance of 7039-T6 material that passed the present standard SCC test and the corresponding property of material that fails the test.

2. The experimental work, which involved producing and testing 7039 material with a wide range of yield strengths, showed that no linear correlation could be found between the SCC resistance of the 7039 material and other characteristics; i.e., yield strength, ballistic performance, and electrical conductivity.

RECOMMENDATIONS

It is recommended that:

1. Additional work concerning relationships between SCC resistance and other 7039-T6 characteristics (yield strength, ballistic performance, and electrical conductivity) should not be performed at this time because any variation in strength which might exist in commercially produced 7039-T6 material does not produce a discernable difference in properties such as ballistic protection and SCC resistance. However, if more refined techniques for measuring these parameters become available, then additional work should be carried out.

2. A study similar to the present task should be conducted on other weldable aluminum alloys that can provide a much wider range of strengths. Examples of such alloys are X7007 and Kalshield. Both alloys are in the T6 temper and have much higher strengths than 7039-T6.

APPENDIX A

Formulas Used in Statistical Calculations

Correlation Coefficient (r)

$$r = \sqrt{\frac{\left[n\Sigma xy - (\Sigma x)(\Sigma y)\right]^2}{\left[n\Sigma x^2 - (\Sigma x)^2\right]\left[n\Sigma y^2 - (\Sigma y)^2\right]}}$$

where

n = number of tests
x = first parameter (i.e., yield strength)
y = second parameter (i.e., number of SCC failures)

F Ratio

$$F = \frac{\sum_j n_j (\overline{X}_j - \overline{X})^2 / (j - 1)}{\Sigma (X_i - \overline{X})^2 - \sum_j n_j (\overline{X}_j - \overline{X})^2 / (n - j)}$$

where

n_j = total sample size in j column

$\overline{X}_j$ = average value of parameter (i.e., yield strength) in j column

X_i = value of individual parameter in i row

n = total sample size

j = number of columns

$\overline{X}$ = grand mean of parameter

Student t Test

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_p \sqrt{(1/N_1) + (1/N_2)}}$$

where

$$S_p = \frac{(N_1 - 1)\ s_1^2 + (N_2 - 1)\ s_2^2}{N_1 + N_2 - 2}$$

where

N_1 = number of passed material

N_2 = number of failed material

s_1 = standard deviation of parameter (i.e., yield strength) of passed material

s_2 = standard deviation of parameter (i.e., yield strength) of failed material

$\overline{X}_1$ = mean value of parameter of passed material

$\overline{X}_2$ = mean value of parameter of failed material

TABLE 1. F Test - Analysis of Variance of Yield Strengths for Ten SCC Categories (0-9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0^{o} Obliquity.

Projectile		Number of SCC Failures Within 4 Days										F Ratio	
		0	1	2	3	4	5	6	7	8	9	Critical**	Calc.
20 mm FS	Y.S.*,ksi	55.9	54.9	54.7	55.5	55.0	54.9	53.3	55.2	55.3	55.7	2.41	1.46
	Stnd. Dev.	2.8	2.4	2.0	2.6	1.4	2.0	0.6	1.8	2.1	1.7		
	Sample Size	93	67	29	34	10	14	5	7	12	5		
Cal.50FS	Y.S.*,ksi	55.7	55.7	54.9	55.1	55.3	55.2	55.6	54.3	55.6	54.1	2.41	0.35
	Stnd. Dev.	2.6	2.8	2.4	2.9	1.9	0.8	1.5	1.7	1.9	1.4		
	Sample Size	40	19	19	25	14	2	6	5	4	3		
Cal.50 APM2	Y.S.*,ksi	54.0	54.9	52.9	53.8	52.6	54.2	59.4	53.2	--	54.9	2.95	1.93
	Stnd. Dev.	1.8	1.2	1.8	1.4	0.6	0.9	0.0	0.3	--	0.7		
	Sample Size	32	4	3	5	2	2	1	2	--	2		
Cal.30 APM2	Y.S.*,ksi	55.9	54.9	54.7	55.5	55.0	54.9	53.3	55.2	55.3	55.7	2.41	1.93
	Stnd. Dev.	2.8	2.4	2.0	2.6	1.4	2.0	0.6	1.8	2.1	1.7		
	Sample Size	93	67	29	34	10	14	5	7	12	5		

* Indicates mean yield strength values
** Confidence level 0.99

TABLE 2. F Test - Analysis of Variance of Weight Merit Ratings, Calculated Against the Steel Standard MIL-S-12560, for Ten SCC Categories (0-9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity.

Projectile		Number of SCC Failures Within 4 Days										F Ratio	
		0	1	2	3	4	5	6	7	8	9	Critical**	Calc.
	WMR*	0.81	0.80	0.80	0.30	0.82	0.81	0.83	0.80	0.79	0.80		
20 mm FS	Stnd. Dev.	0.05	0.04	0.05	0.04	0.04	0.06	0.05	0.05	0.01	0.02	2.41	1.16
	Sample Size	92	65	30	34	9	14	5	7	12	4		
	WMR*	0.90	0.89	0.90	0.89	0.88	0.82	0.89	0.89	0.86	0.87		
Cal.50 FS	Stnd. Dev.	0.04	0.07	0.04	0.05	0.05	0.08	0.05	0.02	0.06	0.04	2.41	0.85
	Sample Size	38	19	16	26	14	2	6	5	4	3		
	WMR*	1.11	1.14	1.13	1.12	1.14	1.12	1.15	1.12	--	1.15		
Cal.50 APM2	Stnd. Dev.	0.03	0.03	0.03	0.03	0.00	0.01	0.00	0.01	--	0.04	2.95	1.02
	Sample Size	32	4	3	5	2	2	1	2	--	2		
	WMR*	1.07	1.07	1.06	1.07	1.06	1.06	1.06	1.06	1.07	1.07		
Cal.30 APM2	Stnd. Dev.	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.04	0.04	0.03	2.41	0.42
	Sample Size	88	59	28	32	11	13	5	7	12	5		

* Indicates mean weight meriting values
** Confidence level 0.99

TABLE 3. F Test - Analysis of Variance of Weight Merit Ratings, Calculated Against the Aluminum Standard MIL-A-46063, for Ten SCC Categories (0-9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0^{o} Obliquity.

Projectile		Number of SCC Failures Within 4 Days										F Ratio	
		0	1	2	3	4	5	6	7	8	9	Critical**	Calc
20 mm FS	WMR*	1.01	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99		
	Stnd. Dev.	0.09	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01	2.41	0.22
	Sample Size	93	67	29	34	10	14	5	7	12	5		
Cal.50 FS	WMR*	0.97	0.96	0.96	0.96	0.96	0.93	0.97	0.97	0.96	0.96		
	Stnd. Dev	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.01	2.41	1.37
	Sample Size	40	19	19	25	14	2	6	5	4	3		
Cal.50 APM2	WMR*	0.97	0.98	0.99	0.97	0.98	0.97	1.00	0.98	--	1.00		
	Stnd. Dev.	0.02	0.03	0.22	0.03	0.00	0.00	0.00	0.01	--	0.04	2.95	1.02
	Sample Size	32	4	3	5	2	2	1	2	--	2		
Cal.30 APM2	WMR*	0.95	0.95	0.94	0.95	0.95	0.95	0.95	0.94	0.95	0.95		
	Stnd. Dev.	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.02	2.41	0.57
	Sample Size	93	60	34	35	11	14	6	7	15	5		

* Indicates mean weight merit rating values
** Confidence level 0.99

TABLE 4. F Test - Analysis of Variance of Velocity Merit Ratings, Calculated Against the Steel Standard MIL-S-12560, for Ten SCC Categories (0-9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity.

Projectile		Number of SCC Failures Within 4 Days										F. Ratio	
		0	1	2	3	4	5	6	7	8	9	Critical**	Calc.
20 mm FS	VMR*	0.84	0.82	0.82	0.83	0.86	0.84	0.88	0.83	0.81	0.80	2.41	1.44
	Stnd. Dev.	0.06	0.07	0.07	0.07	0.06	0.07	0.05	0.07	0.05	0.08		
	Sample Size	91	66	30	35	9	15	5	8	12	4		
Cal.50 FS	VMR*	0.91	0.91	0.93	0.92	0.92	0.86	0.92	0.92	0.90	0.90	2.41	0.72
	Stnd. Dev.	0.04	0.07	0.04	0.04	0.04	0.08	0.04	0.02	0.06	0.04		
	Sample Size	39	19	15	26	14	2	6	5	4	3		
Cal.50 APM2	VMR*	1.06	1.06	1.07	1.07	1.07	1.06	1.08	1.06	--	1.08	2.95	0.92
	Stnd. Dev.	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	--	0.01		
	Sample Size	32	4	3	5	2	2	1	2	--	2		
Cal.30 APM2	VMR*	1.05	1.04	1.04	1.05	1.04	1.04	1.04	1.04	1.05	1.04	2.41	0.48
	Stnd. Dev.	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.01		
	Sample Size	89	57	29	33	10	13	5	7	12	5		

* Indicates mean velocity merit rating values
** Confidence level 0.99

TABLE 5. F Test - Analysis of Variance of Velocity Merit Ratings, Calculated Against the Aluminum Standard MIL-A-46063, for Ten SCC Categories (0-9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity.

Projectile		Number of SCC Failures Within 4 Days										F Ratio	
		0	1	2	3	4	5	6	7	8	9	Critical**	Calc.
20 mm FS	VMR*	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99		
	Stnd. Dev.	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.02	2.41	0.33
	Sample Size	94	69	29	34	10	14	5	7	11	5		
Cal.50 FS	VMR*	0.95	0.95	0.95	0.94	0.95	0.90	0.95	0.96	0.94	0.94		
	Stnd. Dev.	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.01	0.01	2.41	2.07
	Sample Size	40	19	19	25	14	2	6	5	4	3		
Cal.50 APM2	VMR*	0.98	0.99	0.99	0.98	0.99	0.98	1.00	0.98	--	1.00		
	Stnd. Dev.	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.01	--	0.02	2.95	1.10
	Sample Size	32	4	3	5	2	2	1	2	--	2		
Cal.30 APM2	VMR*	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97		
	Stnd. Dev.	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.01	2.41	0.43
	Sample Size	88	57	28	32	10	13	5	7	12	5		

* Indicates mean velocity merit rating values
** Confidence level 0.99

TABLE 6. Student t Test-Analysis of Variance of Yield Strengths for Two SCC Categories (Pass/Fail) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0º Obliquity.

Projectile		SCC Test Passed	SCC Test Failed	Student t Test Critical Region	Student t Test Calc. t
	Y.S.*,ksi	55.4	54.9		
20 mm FS	Stnd. Dev.	2.6	1.9	$-2.6 < t < 2.6$	1.22
	Sample Size	230	43		
	Y.S.*,ksi	55.4	55.0		
Cal.50 FS	Stnd. Dev.	2.6	1.6	$-2.6 < t < 2.6$	0.79
	Sample Size	113	20		
	Y.S.*,ksi	53.9	54.9		
Cal.50 APM2	Stnd. Dev.	1.7	2.2	$-2.7 < t < 2.7$	-1.29
	Sample Size	46	7		
	Y.S.*,ksi	55.4	54.9		
Cal.30 APM2	Stnd. Dev.	2.6	1.9	$-2.6 < t < 2.6$	1.22
	Sample Size	230	43		

* Indicates mean yield strength values

TABLE 7. Student t Test-Analysis of Variance of Merit Ratings, Calculated Against Steel and Aluminum Standards, for Two SCC Categories (Pass/Fail) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0^{o} Obliquity.

Projectile		SCC Test Passed	SCC Test Failed	Student t Test Critical Region	Calc. t
20 mm FS	WMR* (Steel)	0.81	0.80		
	Stnd. Dev.	0.05	0.04	-2.6< t< 2.6	0.43
	Sample Size	230	42		
Cal.50 FS	WMR* (Steel)	0.90	0.88		
	Stnd. Dev.	0.05	0.05	-2.6< t< 2.6	1.68
	Sample Size	113	20		
Cal.50 APM2	WMR* (Steel)	1.11	1.13		
	Stnd. Dev.	0.03	0.02	-2.7< t< 2.7	-1.20
	Sample Size	46	7		
Cal.30 APM2	WMR* (Steel)	1.07	1.06		
	Stnd. Dev.	0.03	0.03	-2.6< t< 2.6	0.64
	Sample Size	2.13	42		
20 mm FS	WMR* (7039)	1.04	1.00		
	Stnd. Dev.	0.60	0.02	-2.6< t< 2.6	0.45
	Sample Size	233	43		
Cal.50 FS	WMR* (7039)	0.96	0.96		
	Stnd. Dev.	0.02	0.02	-2.6< t< 2.6	0.90
	Sample Size	117	20		
Cal.50 APM2	WMR* (7039)	0.97	0.98		
	Stnd. Dev.	0.02	0.02	-2.7< t< 2.7	-1.33
	Sample Size	46	7		
Cal.30 APM2	WMR* (7039)	0.95	0.95		
	Stnd. Dev.	0.03	0.03	-2.6< t< 2.6	0.67
	Sample Size	233	47		

* Indicates mean weight merit rating values

TABLE 8. Student t Test-Analysis of Variance of Velocity Merit Ratings, Calculated Against Steel and Aluminum Standards, for Two SCC Categories (Pass/Fail) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity.

		SCC Test		Student t Test	
Projectile		Passed	Failed	Critical Region	Calc. t
20 mm FS	VMR* (Steel)	0.83	0.83		0.04
	Stnd. Dev.	0.07	0.06	$-2.6 < t < 2.6$	
	Sample Size	227	44		
Cal.50 FS	VMR* (Steel)	0.92	0.91		
	Stnd. Dev.	0.05	0.04	$-2.6 < t < 2.6$	1.11
	Sample Size	113	20		
Cal.50 APM2	VMR* (Steel)	1.06	1.07		
	Stnd. Dev.	0.01	0.01	$-2.7 < t < 2.7$	-1.12
	Sample Size	46	7		
Cal.30 APM2	VMR* (Steel)	1.05	1.04		
	Stnd. Dev.	0.02	0.02	$-2.6 < t < 2.6$	0.79
	Sample Size	218	42		
20 mm FS	VMR* (7039)	1.00	1.00		
	Stnd. Dev.	0.03	0.03	$-2.6 < t < 2.6$	0.96
	Sample Size	238	42		
Cal.50 FS	VMR* (7039)	0.95	0.94		
	Stnd. Dev.	0.02	0.02	$-2.6 < t < 2.6$	0.90
	Sample Size	117	20		
Cal.50 APM2	VMR* (7039)	0.98	0.99		
	Stnd. Dev.	0.01	0.01	$-2.7 < t < 2.7$	-1.23
	Sample Size	46	7		
Cal.30 APM2	VMR* (7039)	0.97	0.97		
	Stnd. Dev.	0.02	0.02	$-2.6 < t < 2.6$	0.25
	Sample Size	215	42		

* Indicates mean velocity merit rating values

TABLE 9. Tensile Properties, Ballistic Performance, Electrical Conductivity, and Stress Corrosion Characteristics of Selected Tempers of 7039 Aluminum Armor Plate.

Material and Temper	Long-Transverse Strength Y.S. (ksi)	Long-Transverse Strength U.T.S. (ksi)	Conductivity % IACS	Projectile and Ballistic Limit (ft/sec)	Time-to-Failure Days 3.5% NaCl, A.I.	Stress Corrosion Acceptance
Plate No. 1-ATAC #485151						
As-received - T6	51.6	59.5	38.0	FS 1971-Passed AP 2336-Passed	8,11,14,14,15,21,21,26	Passed
Sol. T., Age 175/16[a] + 240/48	59.5	67.6	36.0	FS 2043-Passed AP 2447-Passed	4,4,7,7,7,8,9,10,14	Passed
Plate No. 2-ATAC #485151						
As-received - T6	52.6	60.7	38.2	FS 1959-Passed AP 2351-Passed	Not performed	
Sol. T., Age 250/24	53.3	62.4	36.1	FS 2042-Passed AP 2409-Passed	7,7,7,7,7,7,8,16,16	Passed
Sol. T., Age 300/16	51.2	59.6	38.5	FS 1973-Passed AP 2347-Passed	3,3,3,4,4,7,7,7,7	Failed
Kaiser - #333459						
As-received - T64	53.3	62.0	35.0	FS 2025-Passed AP 2410-Passed	7,9,15,23,27,28,66,118	Passed
Kaiser - #336389						
As-received - T64	54.8	63.7	38.5	FS 1999-Passed AP 2334-Passed	5,5,5,6,6,10,10,10,17	Passed

(a) °F/hrs

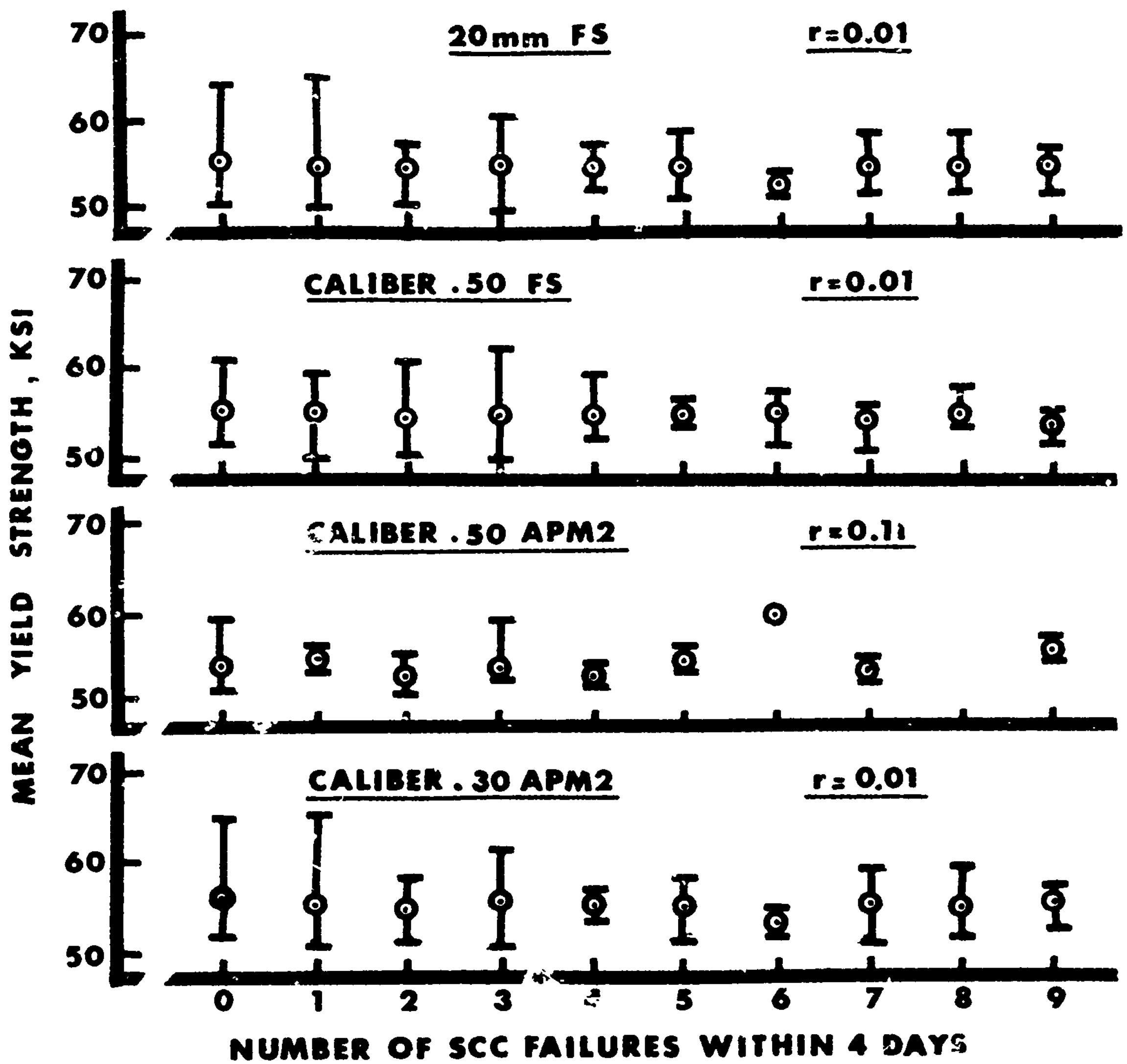

Figure 1 Comparison of Mean Yield Strengths for Ten SCC Categories (0 - 9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity. (r = Correlation Coefficient)

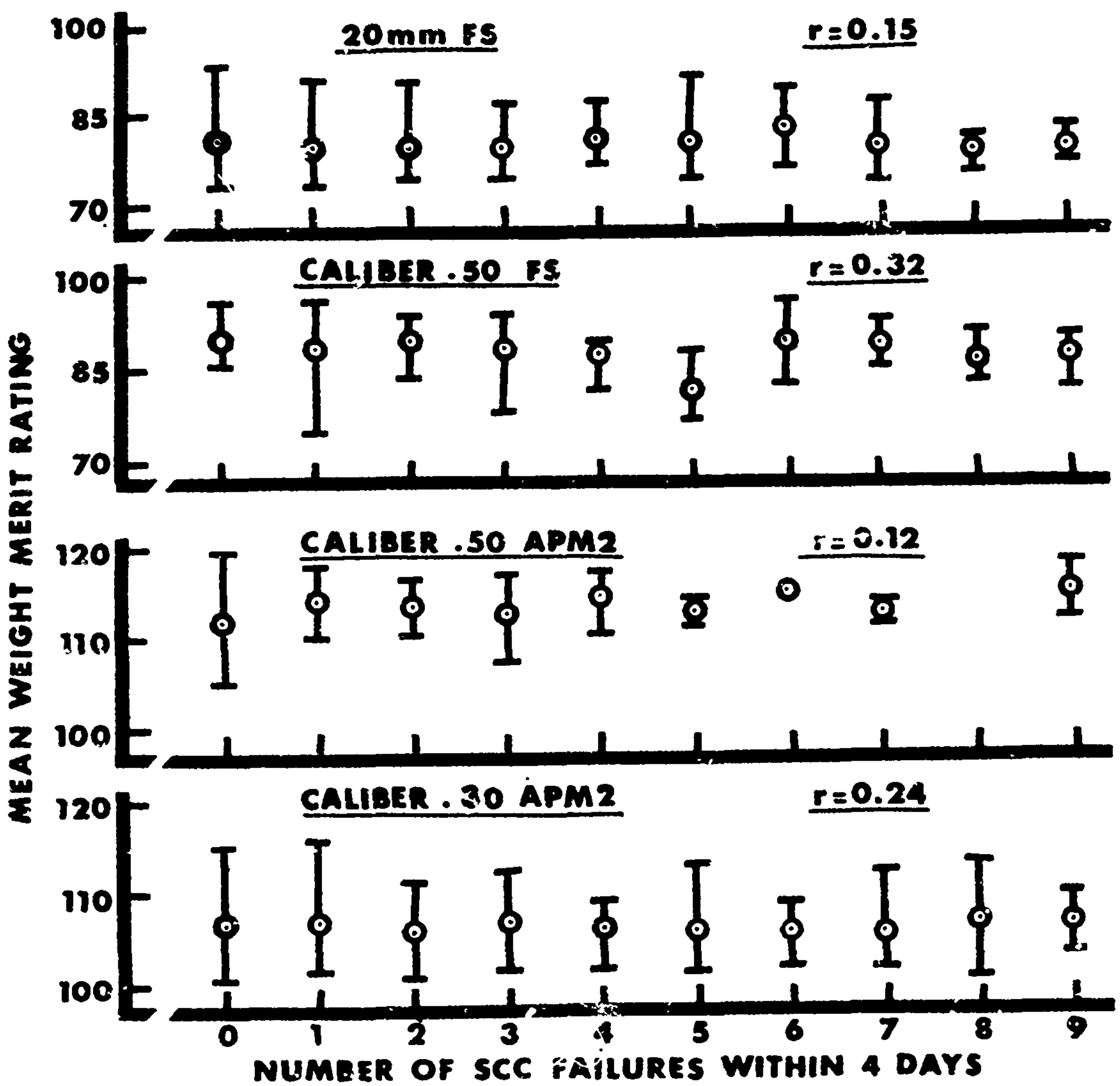

Figure 2 Comparison of Mean Weight Merit Ratings, Calculated Against the Steel Standard MIL-S-12560, for Ten SCC Categories (0 - 9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity. (r = Correlation Coefficient)

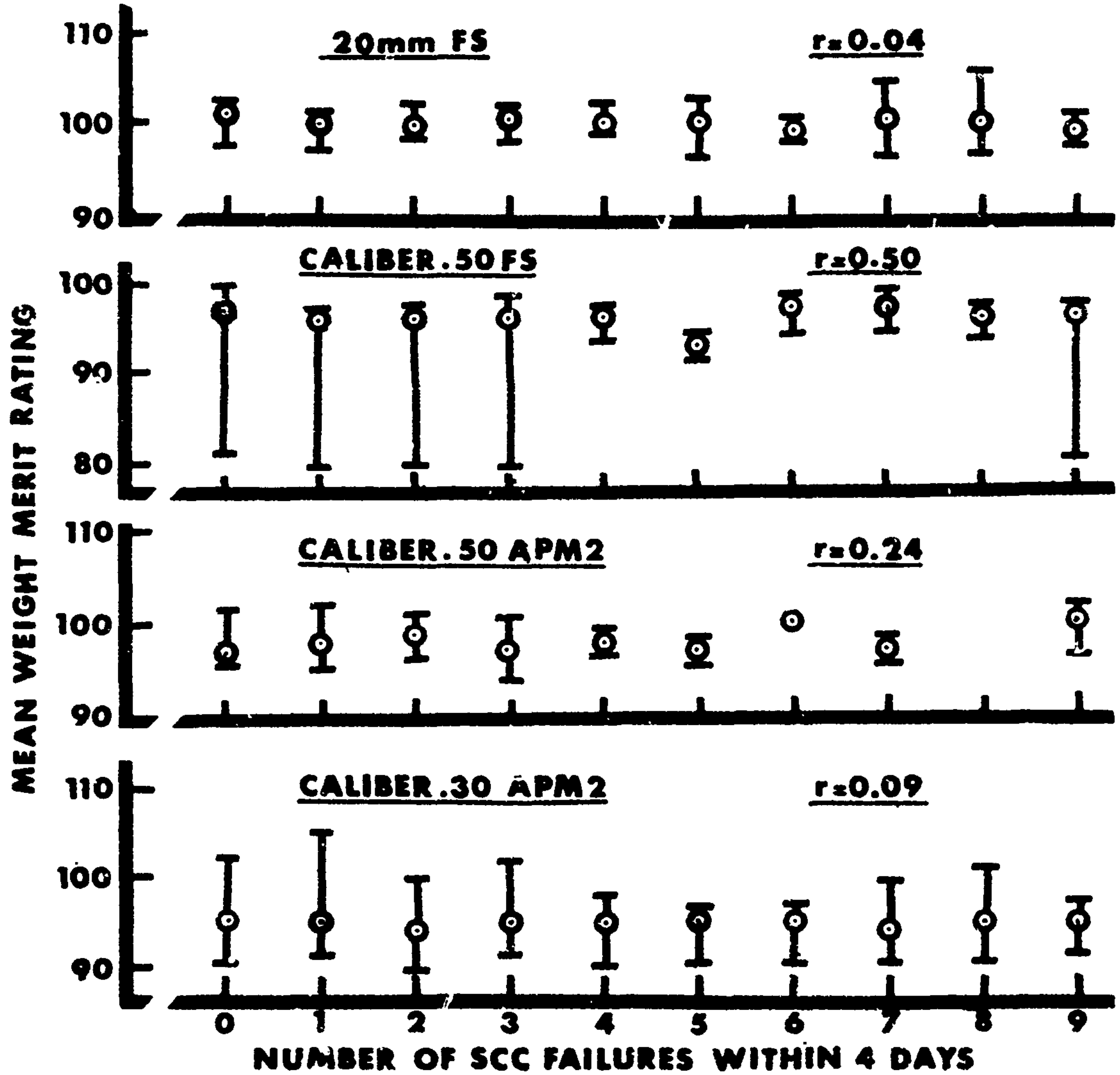

Figure 3 Comparison of Mean Weight Merit Ratings, Calculated Against the Aluminum Standard MIL-A-46063, for Ten SCC Categories (0 - 9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity. (r = Correlation Coefficient)

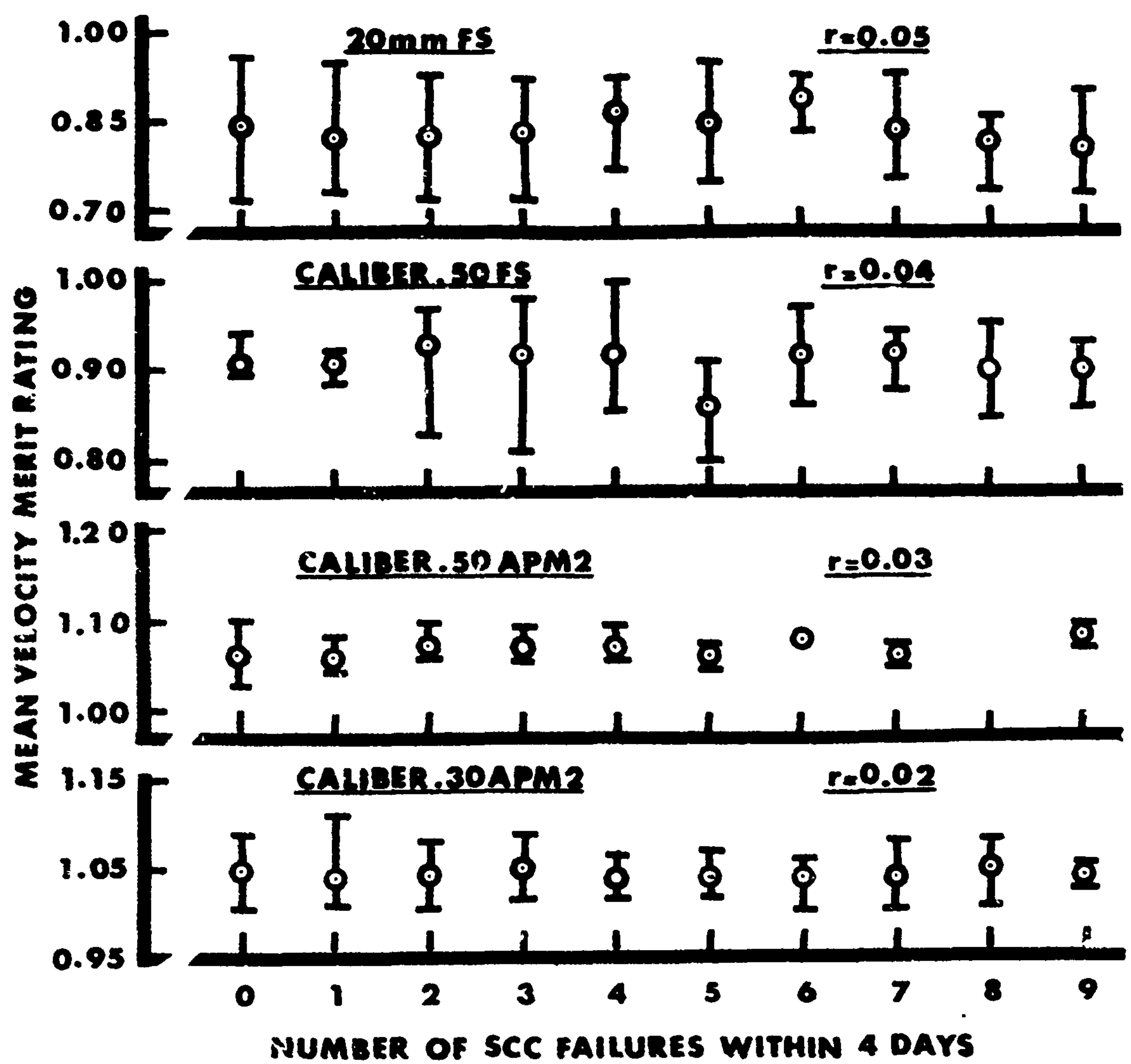

Figure 4 Comparison of Mean Velocity Merit Ratings, Calculated Against the Steel Standard MIL-S-12560, for Ten SCC Categories (0 - 9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity. (r = Correlation Coefficient)

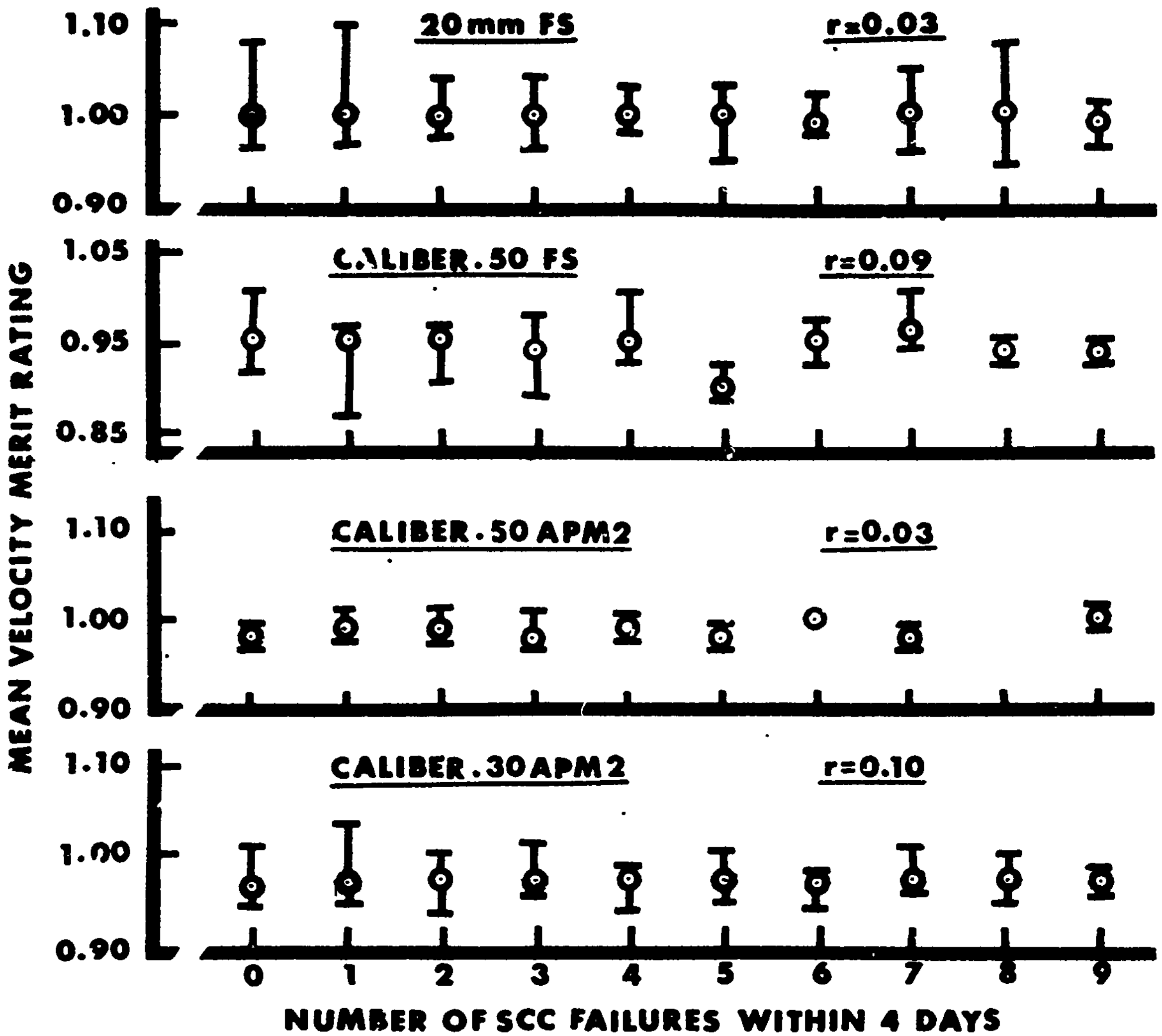

Figure 5 Comparison of Mean Velocity Merit Ratings, Calculated Against the Aluminum Standard MIL-A-46063, for Ten SCC Categories (0 - 9 Failures) of 7039-T6 Aluminum Armor Plates Ballistically Tested Against Selected Small Arms Projectiles at 0° Obliquity. (r = Correlation Coefficient)