ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICH.

REPORT

ON

INFLUENCE OF PROTECTIVE COATINGS ON THE RUPTURE PROPERTIES OF "17-22-A"V, MODIFIED TYPE 403, AND 422 ALLOYS IN SHEET FORM

(PHASE IV)

by

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Project 2536

December 31, 1957

Curtiss-Wright Corporation
Wright Aeronautical Division
Wood-Ridge, New Jersey

INFLUENCE OF PROTECTIVE COATINGS ON THE RUPTURE PROPERTIES OF "17-22-A"V, MODIFIED TYPE 403, AND 422 ALLOYS IN SHEET FORM (PHASE IV)

The influence of protective coatings on the properties of three heat-treatable ferritic alloys in sheet form was evaluated by rupture tests. Two coatings, Solar Alcote and Al-Dip Coating by Arthur Tickle Engineering Company processes, were used on "17-22-A"V steel sheet for test temperatures of 1100°, 1200° and 1300°F. Modified Type 403 stainless steel sheet was evaluated at 1100° and 1200°F with these two coatings plus a sprayed Colmonoy coating applied by Metallizing Engineering Company. The investigation also included 422 stainless steel sheet at 1100° and 1200°F with Solar Alcote. Comparative properties were established for the uncoated condition at the same temperatures and at 900° and 1000°F for the Modified Type 403 and 422 alloys.

The evaluations were based on rupture strengths for 20, 80 and 300 hours. Standard heat treatments were applied to the specimens of uncoated alloys. For the coated specimens, the thermal treatments required for applying the coatings occurred after the standard heat treatments.

SUMMARY AND CONCLUSIONS

There was surprisingly little difference in strength and ductility between coated and uncoated specimens for 20, 80 and 300 hours. The two largest exceptions were:

1. The slopes of the stress-rupture time curves at 1300°F were considerably less for the coated than for uncoated condition in "17-22-A"V sheet. Presumably this resulted from protection against the rather rapid rate of oxidation of this steel at 1300°F. However, the material coated by the Arthur Tickle Al-Dip process was considerably stronger than that with the Solar Alcote. The uncoated condition was equal in strength to the Arthur Tickle coated material at 20 hours and fell to that of the Solar Alcote at 300 hours. Thus the influence of the coatings between 20 and 300 hours at 1300°F was no larger than the influence of thermal treatments during coating on the properties of the alloy .

2. The 422 alloy sheet with the Solar Alcote was substantially lower in rupture strength at 1100° and 1200°F than the uncoated condition. Presumably this was due to the effects of the thermal treatments during coating on the properties of the base material. The information supplied, however, did not explain why a similar effect was not evidenced for the Modified Type 403 steel. The data indicated that the Solar Alcote condition would have had inferior properties to the Arthur Tickle coated and uncoated conditions of "17-22-A"V sheet for time periods longer than 300 hours at 1100° and 1200°F. Presumably this was mainly due to structural differences in the base material caused by thermal treatment conditions during coating. The evidence is not, however, definite and there may have been factors associated with the coatings themselves involved.

Aluminum coatings would be expected to have major benefits where their high oxidation resistance protected the specimens during testing from surface oxidation. Because "17-22-A"V steel is a less oxidation resistant than the two

12 Cr type steels in the investigation and because it was tested at 1300°F, it would be expected to be most improved by the coatings, as was found. It appeared, however, that even in this case for time periods up to 300 hours other factors were just as effective in altering properties as the coatings. The Modified Type 403 and 422 sheet probably had sufficient oxidation resistance so that the protection from the coatings had little effect in time periods up to 300 hours at 1100° and 1200°F.

EXPERIMENTAL MATERIALS

The materials used to evaluate the effects of protective coating are described in Table 1. The heat numbers, chemical compositions and thickness values are those reported to the University by the Wright Aeronautical Division. It was further reported that the sheets had been heat treated as listed in Table 1.

Specimens were taken transverse to the direction of rolling of the sheet. The specimens were 22-inches long with a 0.5-inch wide by 2-inch long gage length at the center. WAD machined and heat treated the specimens and carefully measured the dimensions of the gage section before coating.

Both coated and uncoated specimens were supplied for the investigation.

The information supplied regarding the three types of coatings investigated was as follows:

1. Solar Alcote by the Solar Aircraft Company, San Diego, California.

   Coating S10-99A was applied by dipping for 25 minutes at 1400°F and then "diffusing" for 15 minutes at 1250°F.

2. Al-Dip Coating by Arthur Tickle Engineering Works, Brooklyn, New York.

   The coating was a 12-percent silicon alloy per WAD 5757 diffused at 1250°F.

3. Metallizing Engineering Company, Westburg, Long Island, New York

   Colmonoy alloy (AMS 4775) was sprayed and fused at approximately 2000°F.

The coatings were applied to the alloys investigated as follows:

1. Solar Alcote

   "17-22-A"V
   Modified Type 403 (WAD 8105)
   422 Alloy (WAD 8107)

2. Arthur Tickle Engineering Works Al-Dip

   "17-22-A"V
   Modified Type 403 (WAD 8105)

3. Metallizing Engineering Company's Colmonoy Coating

   Modified Type 403 (WAD 8105)

The original program included the Al-Dip coating (by Arthur Tickle Engineering Works) for the 422 alloy. This material was deleted from the program due to procurement difficulty. The Metallizing Engineering Company coating was only planned for the Modified Type 403 material. A coating by the Chicago Vitreous Company was to be included for all three alloys; but was deleted when the coated specimens were found to have numerous flaws.

PROCEDURE

Evaluation of the coatings was based on rupture-test results for uncoated and coated specimens. Both coated and uncoated specimens of "17-22-A"V steel were tested at 1100°, 1200° and 1300°F. The Modified Type 403 and the 422 steels were tested at 1100° and 1200°F in both conditions and at 900° and 1000°F in the uncoated condition.

The rupture tests were conducted in single-specimen units. Stresses were applied by simple beams except for those test conditions in which the required load was so low that direct dead-weight loading could be used. In conducting the tests the following general procedure was used:

1. The specimens were set-up in the rupture units and the furnace brought to within 50°F of the test temperature between 4:00 and 5:00 p.m.

2. The temperature was equalized overnight and adjusted the next day so that variation along the gage length and from the nominal test temperature was less than ±3°F.

3. Temperature adjustments were completed so that the stress was applied by 1:00 p.m. The stress and required loads were based on the dimensions of the specimens before coating as supplied by WAD.

4. An automatic timer was started at the time the load was applied to measure the rupture time.

5. Elongation values were obtained by measuring the change in the gage length after rupture. Punched gage marks were not used, the changes in the measured length of the 0.5-inch wide portion of the gage length being used instead. No creep data was taken.

RESULTS

The data from the rupture tests on "17-22-A"V steel, Table 2, were used to plot the stress-rupture time curves of Figure 1. Similar curves for the Modified Type 403 steel, Figure 2, were based on the data in Table 3. The data in Table 4 was used to plot the curves of Figure 3 for the 422 alloy. Rupture strengths for 20, 80 and 300 hours derived from the curves of Figures 1, 2 and 3 are included in Tables 2, 3 and 4 and are shown graphically as a function of temperature by Figures 4, 5 and 6.

The results for each alloy are presented in detail in the following three sections of the report.

"17-22-A"V Alloy Sheet

The rupture strengths for the uncoated and coated sheet were established (Table 2 and Fig. 1) at 1100°, 1200° and 1300°F. The results show that:

1. Rupture strengths decreased markedly with increasing temperature (Fig. 4).

2. Over the time range of 20 to 300 hours at 1100°F there was very little difference in rupture strength and ductility between uncoated and coated specimens, or between Solar Alcote or Arthur Tickle Al-Dip coatings. The coated specimens were slightly weaker at short-time periods. Those coated by the Solar Alcote process appeared to be falling off in strength more than the other coating or the uncoated material at the longer-time periods.

3. When tested at 1200°F, the drop in strength at the longer-time periods for the Solar Alcote specimens was more marked than at 1100°F. The Al-Dip coating by the Arthur Tickle process also appeared to have a steeper stress-rupture time curve at the longer time periods so that a slight superiority in strength between 20 and 300 hours, disappeared at 300 hours.

There was no marked difference in ductility and all three conditions had high ductility in the rupture tests.

4. When tested at 1300°F, the Al-Dip coating by the Arthur Tickle process had a stress-rupture time curve parallel to that for the Solar Alcote but at a substantially higher stress level. The uncoated condition started out with high strength but had a steeper stress-rupture time curve than for the coated specimens. Thus the uncoated had rupture strength equal to that of the Arthur Tickle Al-Dip coated specimens at 20 hours and fell to the strength of the Solar Alcote specimens at 300 hours.

Again all three materials had high and similar ductilities.

5. The differences in rupture strength for 20, 80 or 300 hours ranged between 1000 and 3000 psi with the most common difference being about 2000 psi.

Modified Type 403 Sheet

The rupture properties of the uncoated condition were evaluated at 900°, 1000°, 1100° and 1200°F (Table 3 and Fig. 2). All three coatings were evaluated at 1100° and 1200°F.

Rupture strength decreased quite uniformly over this temperature range (Fig. 5). Rupture strength differences between uncoated and coated specimens or between the three-coating processes were of the order of 2500 psi or less at 1100° and 1200°F. The curve of Figure 2 at 1200°F for the Solar Alcote process was drawn to show the lowest possible strength indicated by the data.

Ductility of the uncoated specimens increased from about 12 percent at 900°F to about 25 percent at 1200°F. The Solar Alcote did not change ductility at 1100° and 1200°F. The Arthur Tickle Al-Dip coating tended to increase ductility particularly at 1200°F. The Metallizing Engineering Company Colmonoy coating increased ductility substantially, except for one specimen tested at 1200°F which had both low strength and ductility.

422 Alloy Sheet

The rupture strength of the uncoated sheet (Table 4 and Fig. 3) decreased directly with increasing temperature (Fig. 6). The material with the Solar Alcote coating had substantially lower strength than the uncoated condition at 1100° and 1200°F. There was not much change in ductility in the rupture tests with test temperature or as a result of coating.

The stress dependency of rupture time was very small at 900° and 1000°F. At 1200°F, there was a considerable increase in the slope of the stress-rupture time curves for both uncoated and coated specimens, at least for time periods longer than 50 to 80 hours.

DISCUSSION

The Solar Alcote and Al-Dip coating by Arthur Tickle Engineering Company were definitely in the class of so-called aluminum coatings. It is understood that the Colmonoy coating applied by the Metallizing Engineering Company was also an aluminum base coating.

Aluminum coating could be expected to influence rupture properties by prevention of reduction in strength and ductility associated with ductility. In the test results, however, consideration must be given to the possible alteration of properties of the base material as a result of the thermal treatments required to apply the coatings changing the metallurgical structure from that of the uncoated condition.

The only case where there was a substantial effect on rupture strength was the lower strength of the 422 material with the Solar Alcote. Because it is presumed that the coating would tend to offset damage from oxidation, it is presumed that the strength of the base material must have been reduced by the thermal treatments during application of the coating. Yet it is difficult to understand why the thermal treatment associated with coating of this material should have had so much effect on the 422 alloy when there was little apparent effect on the Modified Type 403 material. The reported conditions of heating for coating was the same in both cases and both alloys would be expected to respond in a similar manner.

The slopes of the curves for the tests on "17-22-A"V material at 1300°F indicated that the coatings were probably helping to maintain strength by reducing surface deterioration by oxidation. The issue is, however, clouded by the apparent breaks in the curves at 1100° for Solar Alcote specimens and at 1200°F for both coated materials.

The only case where appreciable beneficial effects seemed indicated by the data was "17-22-A"V sheet at 1300°F. Oxidation of this alloy would be expected to be quite rapid at 1300°F and protection against oxidation would be expected to show benefits. Even in this case, however, alteration of properties of the base metal by thermal treatments associated with coating had as much effect as oxidation protection. This latter observation was based on the differences in strength between the samples coated by the Solar Alcote and Arthur Tickle processes.

Other factors could be involved. It is known that exclusion of oxygen during tests often results in lower creep-rupture properties than for tests conducted in air. A highly oxidation resistant coating could act in this way. The authors, however, know of no case where this effect has been proven for aluminum coating. Also, the coatings would be expected to be weak and possibly brittle. Thus deterioration of the coating by creep might influence results.

Stress for the tests were based on specimen dimensions before coating. So far as is known, this provided a fair basis of evaluation. Certainly it would be better than using dimensions after coating with the increase in thickness due to the weak aluminum alloy coatings.

Only three or four rupture tests were used to evaluate the materials at each temperature. In a number of cases the data were erratic. Both the few tests and the erratic results tended to cast doubt on the exact rupture strengths. However, the results are valid for evaluating the effects of the coatings.

TABLE 1

DESCRIPTION OF EXPERIMENTAL MATERIALS

Material	"17-22-A"V (AMS 6436)	Modified Type 403 (WAD 8105)	Rezistal 422 (WAD 8107)
Heat No.	D14468	4566	142761
Sheet Thickness (inch)	0.062	0.063	0.049
Chemical Composition (Percent)	(AMS 6436 range)		
C	0.20 - 0.25	0.18	0.22
Cr	1.00 - 1.50	12.28	11.71
W			0.93
Si	0.55 - 0.75	0.46	0.36
Ni	0.50 max.	0.12	0.69
Mn	0.60 - 0.90	0.48	0.68
Mo	0.40 - 0.60	1.09	0.94
P	0.040 max.		0.019
S	0.040 max.	0.015	0.018
Va	0.75 - 0.95	0.22	0.26
Cu	0.50 max.		

Note: Actual composition of the "17-22-A"V was not available. The analysis given is the range in AMS 6436.

Specified Heat Treatments for Experimental Materials

Material	Normalizing Conditions Temperature (°F)	Normalizing Conditions Time (hours)	Tempering Conditions Temperature (°F)	Tempering Conditions Time (hours)	Rockwell C Hardness
17-22A(V) (AMS 6436)	1775	0.5	1200	6	26/32
Mod. Type 403 (WAD 8105)	1800	0.5	1100	2	35
Rezistal 422 (WAD 8107)	1900	0.5	1150	2	34

TABLE 2

RUPTURE PROPERTIES OF UNCOATED AND COATED "17-22-A"V STEEL SHEET

(Heat D14468 - AMS 6436)

Coating Process	Test Temperature (°F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)
Uncoated	1100	40,000	0.3	30
		35,000	2.4	27
		35,000	2.5	36
		28,500	24.2	22
		26,000	35.5	32
		21,500	184.9	37
Solar Alcote	1100	29,000	5.0	32
		23,500	120.2	32
		20,000	275.0	39
		18,000	293.5	30
Arthur Tickle	1100	29,000	5.2	35
		23,500	66.6	44
		20,000	272.3	38
		19,000	451.3	26
Uncoated	1200	18,000	18.9	36
		13,000	107.1	30
		11,000	233.9	28
Solar Alcote	1200	19,000	8.7	29
		14,000	66.9	41
		12,000	112.3	32
		9,000	169.0	42
Arthur Tickle	1200	20,000	6.3	42
		16,000	57.4	56
		14,000	104.7	34
		11,000	267.5	32
Uncoated	1300	9,500	23.8	54
		6,500	100.0	69
		5,000	203.0	36
Solar Alcote	1300	8,500	16.9	46
		7,000	30.7	52
		4,500	140.9	42
		3,500	812.7	--
Arthur Tickle	1300	9,500	27.2	26
		7,000	135.5	54
		5,800	536.0	43

TABLE 2 (Concluded)

RUPTURE PROPERTIES OF UNCOATED AND COATED "17-22-A"V STEEL SHEET

(Heat D14468 - AMS 6436)

Rupture Strengths

Coating Process	Test Temperature (°F)	Stress for Rupture (psi) 20-hr	80-hr	300-hr
Uncoated	1100	29,000	24,000	(20,000)
Solar Alcote	1100	26,700	24,500	18,800
Arthur Tickle	1100	26,000	23,000	19,500
Uncoated	1200	17,800	13,500	(10,500)
Solar Alcote	1200	16,800	13,000	(7,800)
Arthur Tickle	1200	17,800	15,100	(10,500)
Uncoated	1300	(10,000)	6,900	(4,400)
Solar Alcote	1300	7,600	5,700	4,300
Arthur Tickle	1300	(9,800)	7,800	6,300

TABLE 3

RUPTURE PROPERTIES OF MODIFIED TYPE 403 STEEL SHEET

(Heat 4566 - WAD 8105)

Coating Process	Test Temperature (°F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)
Uncoated	900	85,000	30.0	14
		77,500	102.1	12
		72,000	358.4	12
Uncoated	1000	63,000	25.3	17
		60,000	29.5	18
		56,000	152.8	16
		52,000	706.1	13
Uncoated	1100	48,000	1.7	18
		35,000	45.0	14
		30,000	70.0	21
		22,500	1309.3	10
Solar Alcote	1100	37,000	5.3	22
		31,000	74.9	16
		26,500	138.4	17
Arthur Tickle	1100	38,000	8.2	22
		33,000	36.5	19
		30,000	171.0	14
		27,000	303.4	16
Metallizing Eng. Co.	1100	35,000	18.8	18
		32,500	14.6	18
		27,000	111.1	17
		22,500	782	17
Uncoated	1200	26,000	2.5	28
		15,000	103.7	24
		12,500	130.6	23
		12,000	171.4	28
Solar Alcote	1200	18,000	19.3	32
		14,000	24.5	20
		11,000	141.0	22
		9,500	383.3	31
Arthur Tickle	1200	17,000	25.9	16
		14,000	70.9	27
		11,000	189.1	36
		9,500	392.0	42
Metallizing Eng. Co.	1200	20,000	11.9	40
		15,000	72.3	40
		11,500	191.2	41
		9,500	233.9	26

TABLE 3 (Concluded)

RUPTURE PROPERTIES OF MODIFIED TYPE 403 STEEL SHEET

(Heat 4566 - WAD 8105)

Rupture Strengths

Coating Process	Test Temperature (°F)	Stress for Rupture (psi)		
		20-hr	80-hr	300-hr
Uncoated	900	(86,500)	79,000	73,000
Uncoated	1000	(62,500)	58,000	54,000
Uncoated	1100	37,000	31,500	27,000
Solar Alcote	1100	34,000	30,500	(21,500)
Arthur Tickle	1100	35,000	31,000	28,000
Metallizing Eng. Co.	1100	34,000	29,000	24,500
Uncoated	1200	17,500	13,800	(11,000)
Solar Alcote	1200	16,500	12,800	10,000
Arthur Tickle	1200	18,500	13,500	10,000
Metallizing Eng. Co.	1200	18,500	14,800	9,500

TABLE 4

RUPTURE PROPERTIES OF 422 ALLOY STEEL SHEET

(Heat 142761 - WAD 8107)

Coating Process	Test Temperature (°F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)
Uncoated	900	90,000	20.7	12
		85,000	69.7	10
		80,000	487.2	11
		76,000	2356.6	10
Uncoated	1000	70,000	11.0	13
		64,000	140.8	11
		60,000	1171.4	10
Uncoated	1100	51,000	21.4	9
		47,000	70.6	8
		43,000	174.2	10
		40,000	303.5	8
Solar Alcote	1100	47,000	3.1	16
		38,000	75.0	10
		34,000	272.1	8
Uncoated	1200	32,500	7.9	10
		26,000	78.1	10
		19,500	143.5	8
		15,000	446.1	10
Solar Alcote	1200	25,000	16.1	12
		21,000	46.2	12
		17,000	94.0	10
		12,000	357.6	10

Rupture Strengths

Coating Process	Test Temperature (°F)	Stress for Rupture (psi)		
		20-hr	80-hr	300-hr
Uncoated	900	90,000	86,000	82,000
Uncoated	1000	68,000	65,500	62,500
Uncoated	1100	52,000	46,000	40,000
Solar Alcote	1100	41,500	38,000	33,500
Uncoated	1200	29,500	26,000	17,000
Solar Alcote	1200	24,000	18,000	12,600

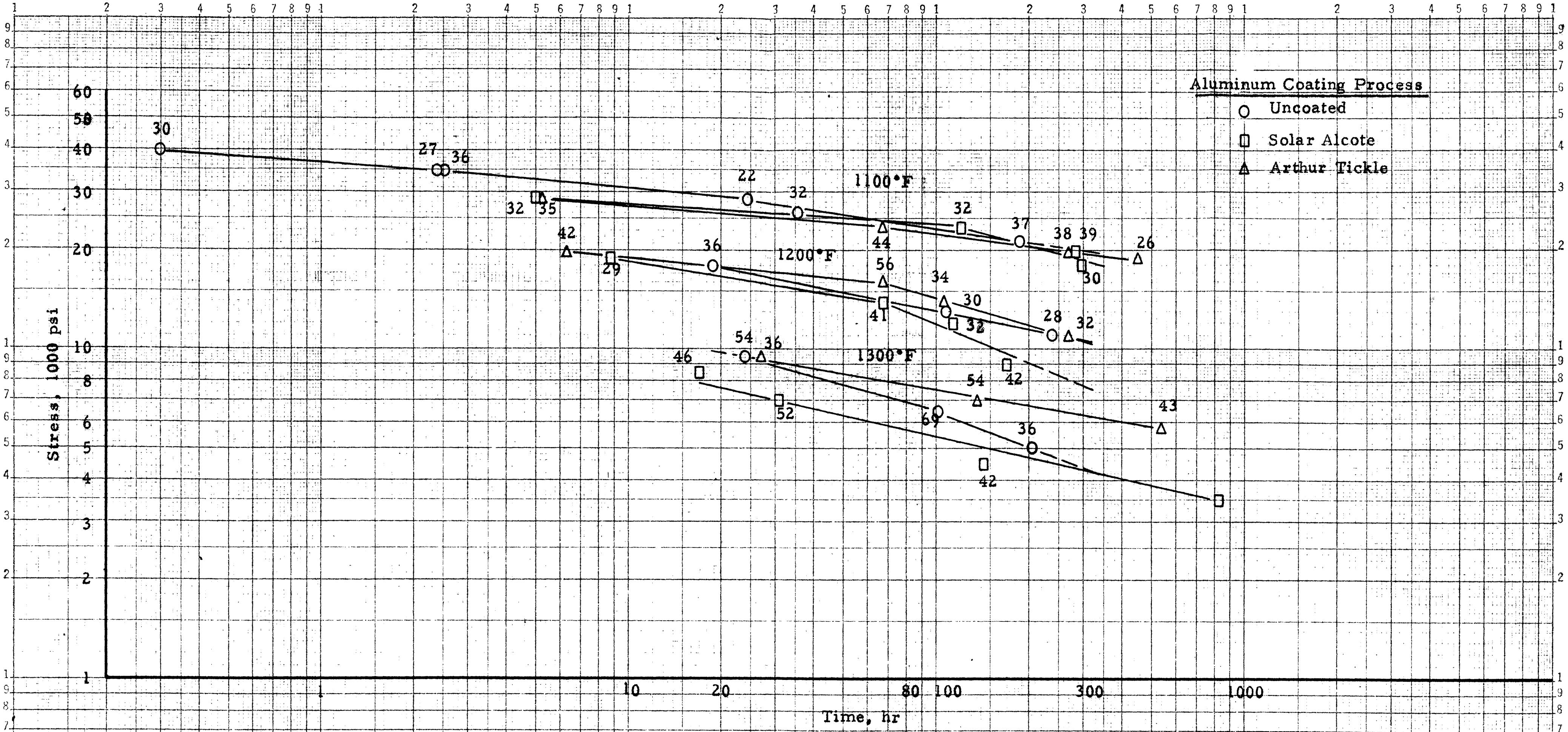

Figure 1. - Stress-rupture time curves at 1100°, 1200° and 1300°F for uncoated and aluminum coated "17-22-A"V alloy sheet.

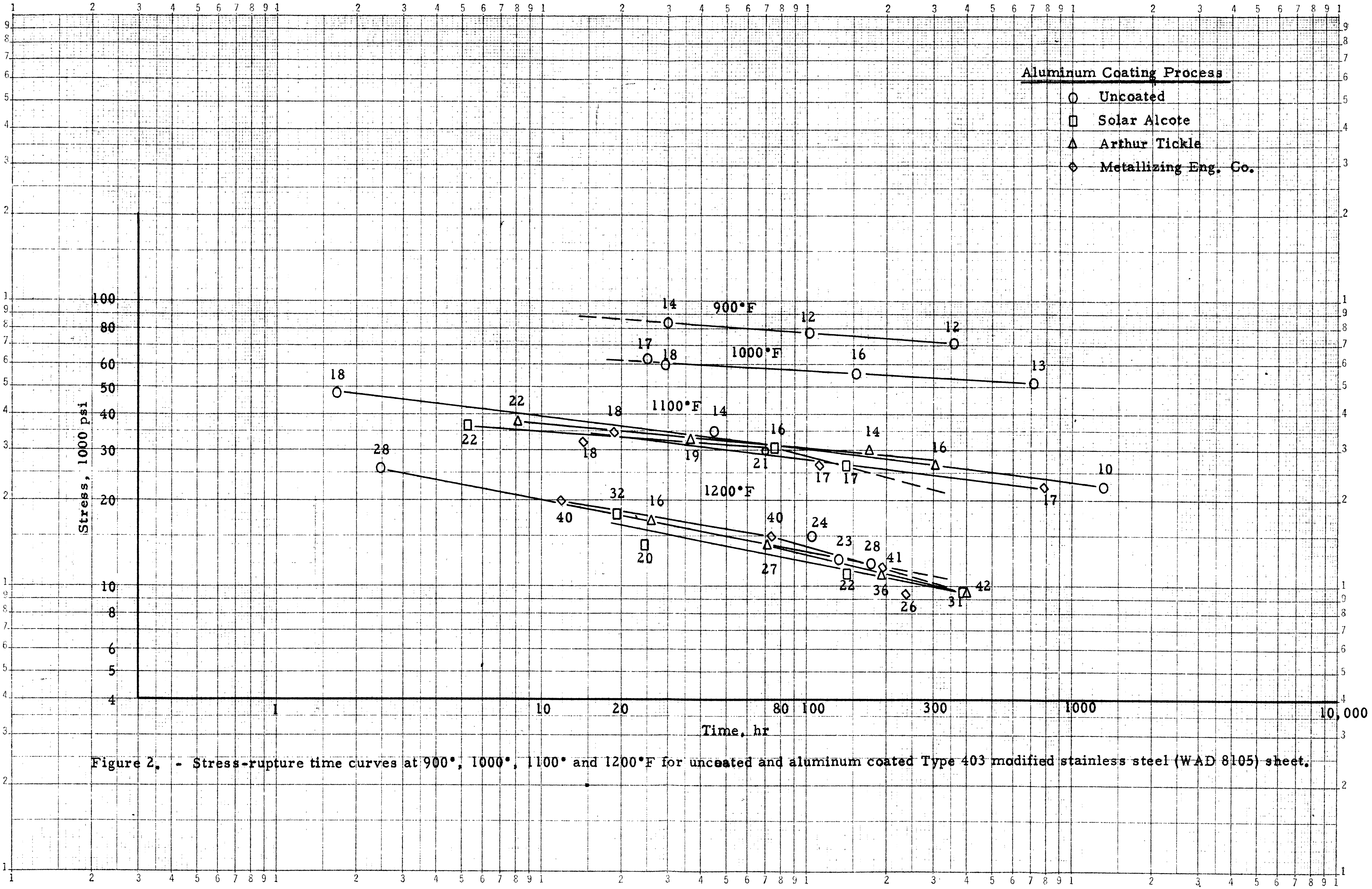

Figure 2. - Stress-rupture time curves at 900°, 1000°, 1100° and 1200°F for uncoated and aluminum coated Type 403 modified stainless steel (WAD 8105) sheet.

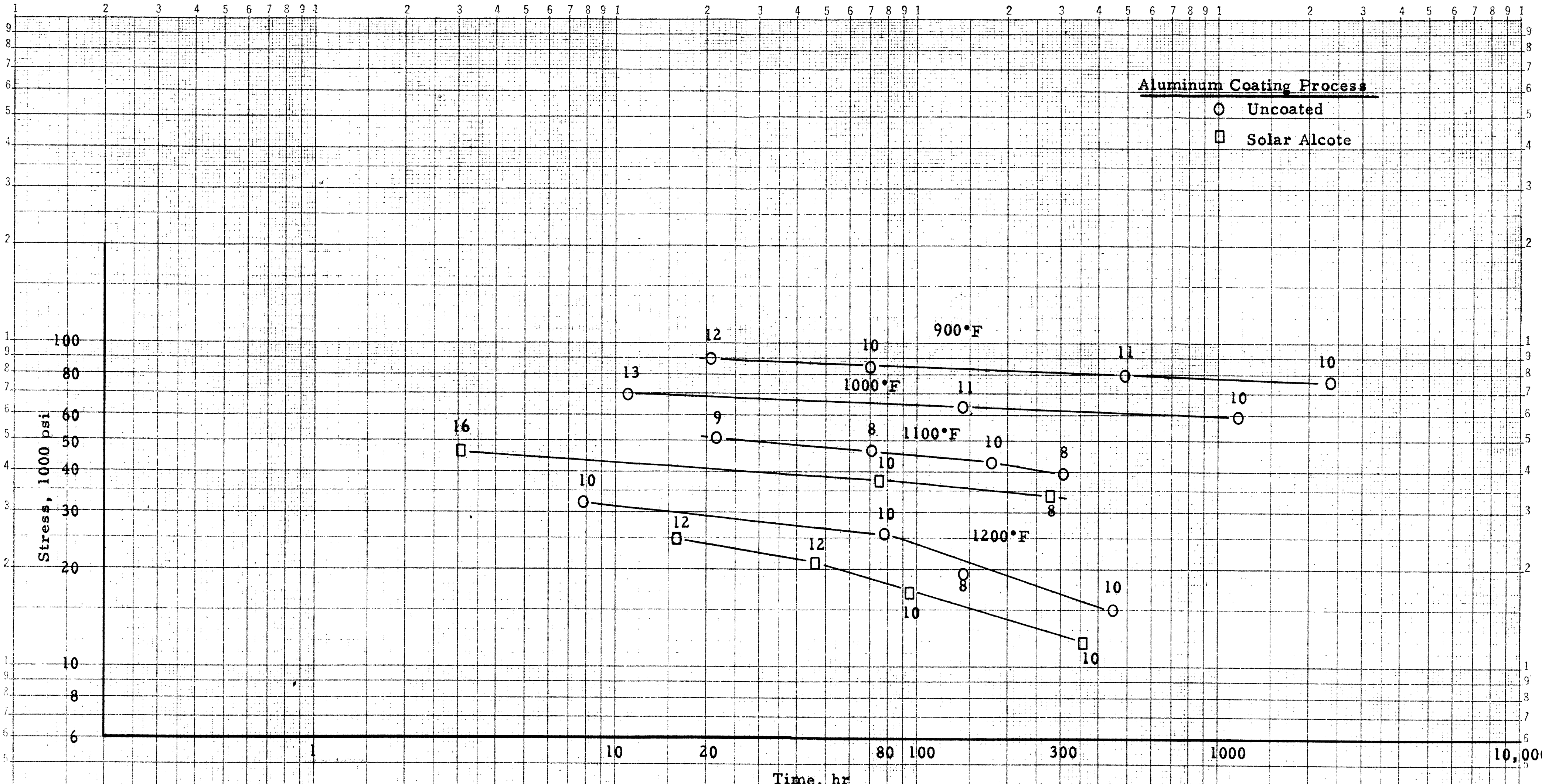

Figure 3. - Stress-rupture time curves at 900°, 1000°, 1100° and 1200°F for uncoated and aluminum coated Rezistal 422 (WAD 8107) sheet.

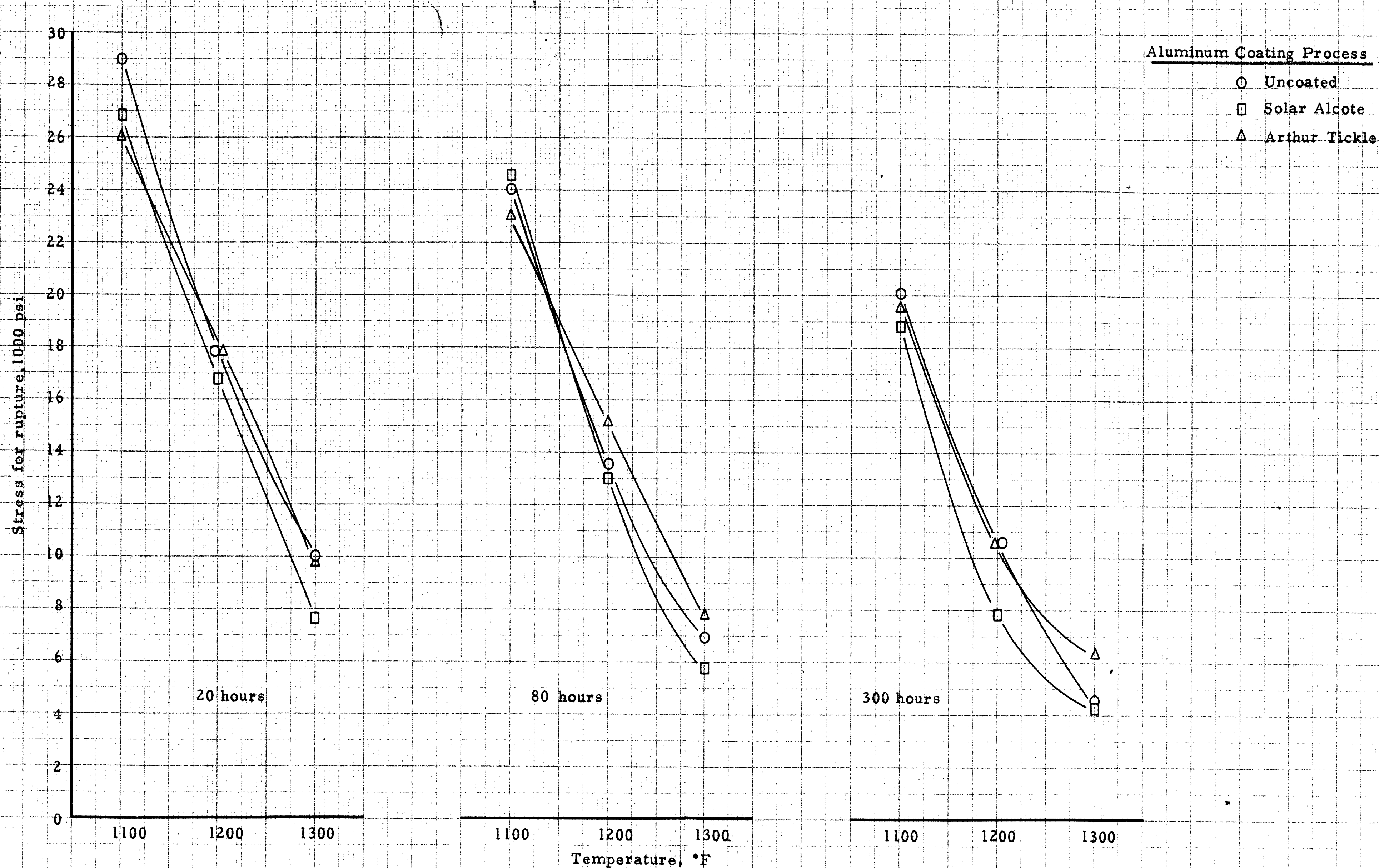

Figure 4. - Influence of temperature on the stress for rupture in 20, 80 and 300 hours for uncoated and aluminum coated "17-22-A"V alloy sheet.

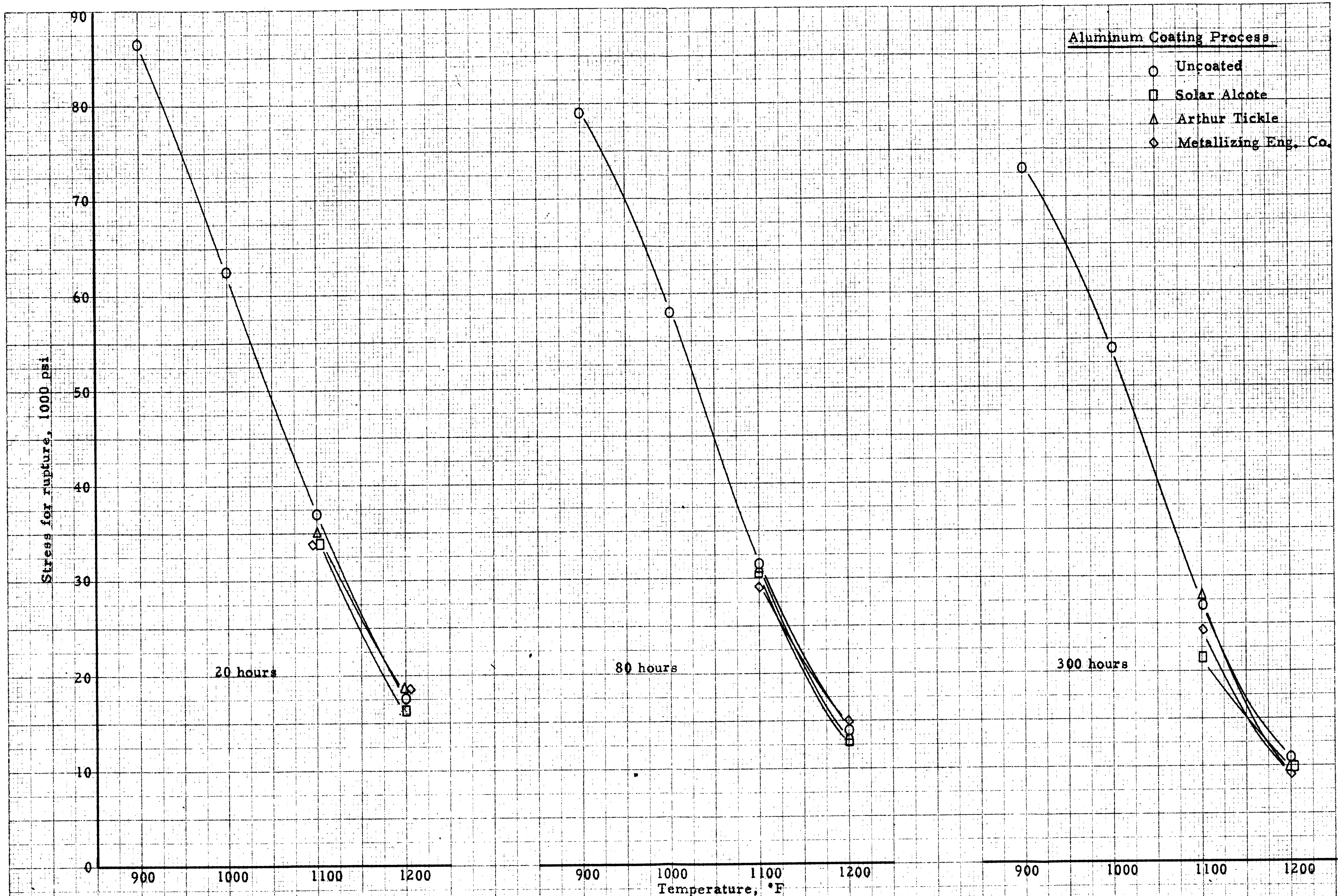

Figure 5. - Influence of temperature on the stress for rupture in 20, 80 and 300 hours for uncoated and aluminum coated Type 403 modified stainless steel (WAD 8105) sheet.

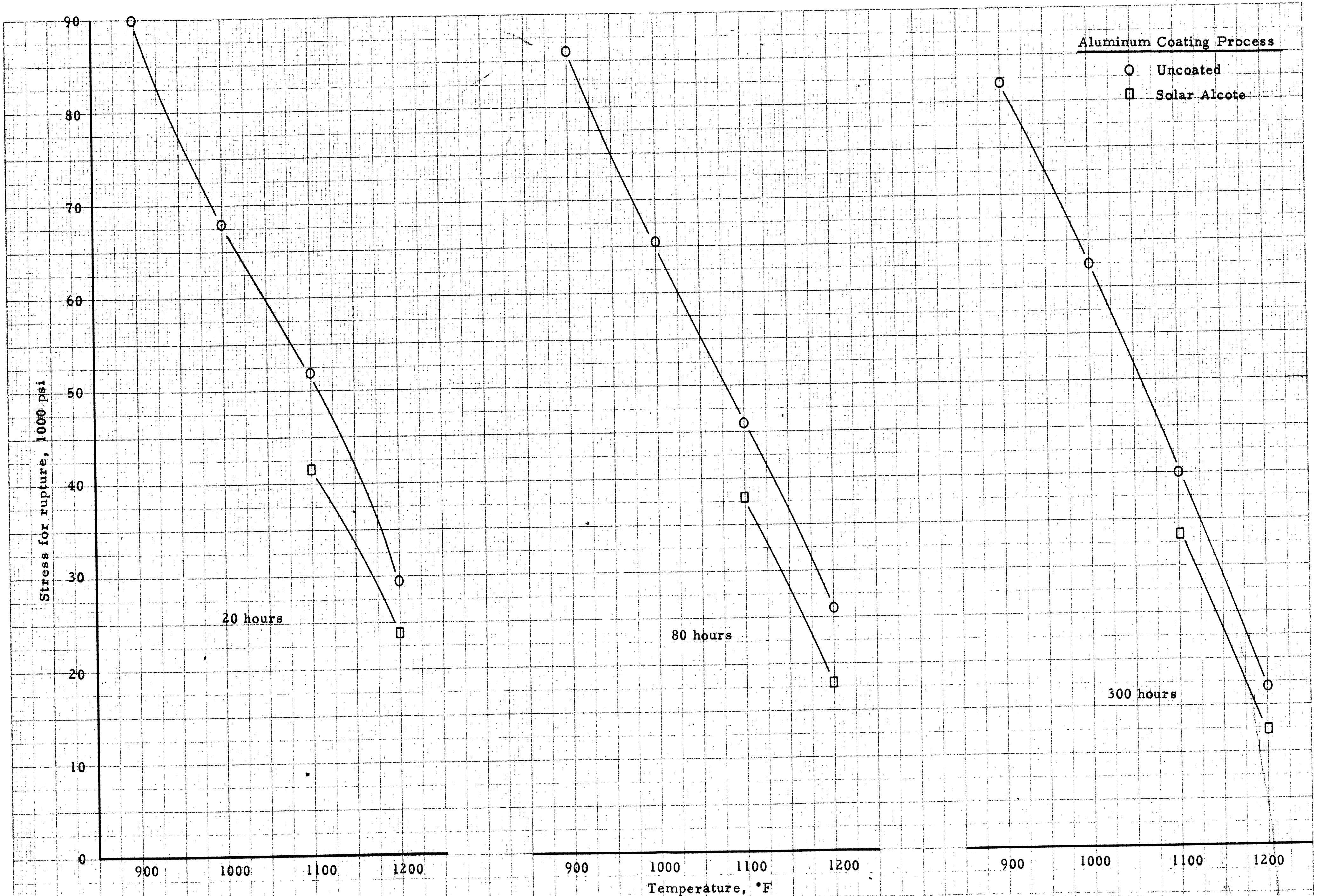

Figure 6. - Influence of temperature on the stress for rupture in 20, 80 and 300 hours for uncoated and aluminum coated Rezistal 422 (WAD 8107) sheet.