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REPORT

ON

THE INFLUENCE OF SIMULATED COLD FORMING AND ANNEALING ON THE PROPERTIES AT 1600°F OF N-155 SHEET MATERIAL

by

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INFLUENCE OF SIMULATED COLD FORMING AND ANNEALING ON THE PROPERTIES AT 1600°F OF N-155 SHEET MATERIAL

Parts made from sheet are commonly formed cold and heat treated to remove the cold work. The process is usually carried out in several steps of cold reduction and intermediate anneals. An investigation was conducted to determine the effect of such treatments on the properties at 1600°F of N-155 sheet material for the Wright Aeronautical Division of the Curtiss-Wright Corporation under Purchase Order FX 399621.

During cold forming the sheet is exposed to a range of deformation from those areas which receive no deformation to the maximum which can be applied in any one step. These conditions were simulated to obtain basic information by heat treating samples cold reduced by rolling. The effects were studied for material with no reduction to a total of 24 percent reduction in area. In each case, the reduction per pass was one fourth of the total reduction with an anneal between each pass as well as after the last pass. This procedure was used on the basis that experience had indicated that the maximum reduction per step in cold forming was of the order of 6-percent reduction in area.

Two series of experiments were carried out. In one, sample, with no reduction or a total reduction of 8 percent (4 passes of 2-percent reduction) were tested for properties at 1600°F after various annealing treatments. Water quenching or furnace cooling from 2100°F, or reheating to 1850°or 1650°F after furnace cooling from 2100°F were the treatments used. In the other series, samples with total reductions varying from 4 to 24 percent were studied at 1600°F with one type of annealing treatment - heating to 2100°F and furnace cooling.

Evaluation of the effects of cold work and annealing was confined to 1600°F because this temperature represented the anticipated service conditions.

Rupture tests were conducted to establish rupture strengths at 20, 80, and 300 hours. Creep data were obtained during the rupture tests to define the time periods for limited deformation under these stresses.

TEST MATERIALS

Machined specimens of N-155 sheet (AMS 5532) material from Heat M1083 were received. Strips, 24-inches long x 1-1/4 inches wide, had been sheared transverse to the rolling direction of the 0.078-inch thick sheet. The sheet had been manufactured by Haynes Stellite Company who reported the chemical composition as follows:

C	Mn	Si	P	S	Cr	Ni	Co	Mo	W	Cb+Ta	N_2	Fe
0.10	1.57	0.78	.019	0.008	21.67	19.56	19.65	3.10	2.48	0.91	0.15	bal.

The blanks were cold rolled to the desired reduction at Wright Aeronautical Division on a single stand mill having 4-inch diameter by 6-inch wide rolls. The desired reduction was achieved in four passes equally divided. In the study of the effect of various annealing operations, the individual annealing operation was performed after each pass. The specimens used in the reduction study were annealed by furnace cooling from 2100°F to 200°F in a hydrogen atmosphere. Table I tabulates the annealing treatment used, the specimen code, the reduction per pass, the number of passes, and the final reduction.

The blanks were machined into specimens with a gage length of 2.25 inches by 0.500 inch in width. The gage length was in the center of 1-inch wide strips 22 inches long.

PROCEDURE

The objectives of the investigation were attained by evaluation of the following properties at 1600°F:

1. Rupture strengths at 20, 80, and 300 hours were established by three stress-rupture tests for each condition.

2. Time-elongation data were taken during each rupture test and creep curves plotted.

3. Stress-time for total deformations of 0.2, 0.5, 1.0, and 2 percent were derived from the creep curves. These values were plotted as curves and total deformation strengths obtained for the time periods of interest. The deformation included the elastic, and any plastic deformation which occurred during application of the stress to the specimens as well as the subsequent creep.

The stress-rupture tests were conducted in single units of the dead weight-beam loaded type, except when low stresses required the use of a direct load.

The following procedure was used to bring the specimens to temperature:

1. The specimens were set up in the units and the heat turned on at 4:00 p.m. to bring the temperature within 50°F of the desired temperature by 5:00 p.m.

2. The specimens were allowed to stand overnight, the temperature raised to 1600°F between 8:00 and 9:00 a.m. the next day.

3. Final adjustments to test temperature and for temperature distribution along the length of the specimen were made so that stress could be applied by 1:00 p.m.

4. Time-elongation data were secured by means of extensometers. Collars were fixed on the upper and lower shoulders of the specimens by means of pins inserted through holes drilled in the specimen shoulder. Extension rods were attached to the collars and extended out of the furnace. Rollers carrying a mirror were inserted between each pair of upper and lower extension rods. As the specimen elongated, the mirrors rotated and the rotation was measured by a scale reflected in the mirrors to a telescope.

The readings on both sides of the specimens were taken and averaged. The sensitivity of the extensometer system was 0.000003 inches per inch in the 2-inch gage length.

Inasmuch as the extensometers were attached to the shoulders, the observed deformation included elongation in the fillets and a portion of the shoulders of the specimen as well as the reduced section. A system of correcting the deformation through a calculated "effective gage length" was used.

RESULTS

The deformation and rupture data obtained at 1600°F are given in Table II and shown as stress versus time curves in Figures 1 through 12. The rupture and total-deformation strengths derived from Figures 1 through 12 are summarized as Table III and Figures 13 through 23.

The data were usually consistent and gave reasonably smooth curves. There were exceptions, however, where the data were somewhat erratic. In such cases either average curves were drawn or the curve was drawn to show the probable true behavior of the material.

Several conditions of heat treatment with or without cold work were studied. The properties after the treatments can be summarized as follows:

Influence of Conditions of Heat Treatment

Treatment at 2100°F, either water quenched or furnace cooled, resulted in the most variation in rupture strength, Figure 13, between material cold reduced 8 percent and material with no cold reduction. These treatments also slightly reduced strength of the material which received no cold reduction. Treatments at 1850°F and particularly at 1650°F after furnace cooling from 2100°F brought the two conditions together at strength levels similar to the original material.

The differences in rupture strength between as-received material heat treated and material cold worked to 8-percent reduction and heat treated were at most 1650 psi and in most cases considerably less. The largest deviations from the strength of the original condition was - 1500 psi for the heat treated condition and + 500 psi for cold worked material. In general, these variations are quite small and no more than the variations commonly encountered between different heats (Reference 1).

The 8-percent cold reduction prior to heat treatment generally increased short time and slightly reduced long time ductility in the rupture tests, Figure 14, in comparison to the as-received condition when heat treated the various ways. The major exception was the very large increase in ductility at all time periods for the as-received material treated first at 2100°F and then at 1650°F. Treatment at 2100°F alone with either water quenching or furnace cooling resulted in about 5-percent less elongation than the as-received material when rupture times were longer than 150 hours. Otherwise elongations were equal to or greater than the as-received condition. The lowest elongation measured was 5 percent.

In nearly every case, the material cold reduced 8 percent had higher deformation strengths, Figures 15 through 18, than the heat-treated material with no reduction. The differences generally were less for the treatments involving heating to 2100°F, furnace cooling, and then reheating to 1850° or 1650°F than for a single treatment at 2100°F. The degree of difference also decreased as the deformation decreased from 2.0 to 0.2 percent. In most cases, the difference in strength was considerably less than the largest difference of 2500 psi for 2-percent total deformation in 5 hours after furnace cooling from 2100°F.

The deformation strengths of the as-received material decreased in all cases as a result of the heat treatments, Figures 15 through 18. Furnace cooling after heating at 2100°F generally gave the lowest strength of the heat treatments considered. There was little change as a result of subsequently heating to 1850° or 1650°F for deformations of 2.0 and 1.0 percent while there was some increase for 0.5 and 0.2 percent deformation in 80 and 300 hours. The decreases were generally considerably less than the 2600 psi for 1-percent deformation in 5 hours after furnace cooling from 2000° and reheating to 1650°F.

The total-deformation strengths of the material cold reduced 8 percent, Figures 15 through 18, were generally closer to that of the as-received material than for the reheated as-received material. Secondly, it was often higher in strength than the as-received condition, except at short-time periods.

Inspection of Figures 15 through 18 show that the inter-relationships of total-deformation strengths at 1600°F to 0 or 8-percent cold reduction with the several heat treatments considered were complex. There were variations in the general trends with both the total deformation and the time period for the deformation. Thus the "optimum" treatment varied depending on the total deformation and time period considered. It should also be recognized that the strength variations were relatively small in most cases. Even the maximum variation in strength of 2600 psi from the as-received condition was no larger, if as large, as is usually expected between heats.

Influence of Amount of Cold Reduction

The amount of change in rupture strength as a result of varying the cold reduction from 0 to 24 percent, Figure 19, was relatively small when subsequently heated to 2100°F and furnace cooled. Reductions of 4 and 8 percent resulted in the same strength as the as-received material. Cold reductions of 16 and 24 percent resulted in strength losses of 500 to 1200 psi from the as-received condition. Actually simply reheating the as-received materials caused just about as much loss in strength as the larger reductions. Again the variations in strength were small in comparison to normal scatter in strength for the material.

Cold deformations of 8, 16, and 24 percent and heat treatment at 2100°F and furnace cooling resulted in some loss in rupture test ductility, Figure 20, in comparison to the as-received condition. There was little change from the as-received condition for cold reductions of 0 and 4 percent. The maximum decrease in ductility was from 5 to 6 percent for rupture in about 200 hours. Minimum values were around 7-percent elongation. These differences were also small in comparison to normal scatter between heats.

The total-deformation strengths generally showed a little change or a slight increase, Figures 21 through 24, from the combination of cold reductions of 4 or 8 percent and heating at 2100°F with furnace cooling. The strengths were somewhat reduced by reductions of 16 and 24 percent. Simply reheating the as-received material caused about as much reduction in deformation strength as cold reductions of 16 and 24 percent. These reductions were no more than 2000 psi and usually less for the deformations and time periods considered. The only exceptions were the total deformation strengths for 1-percent deformation in 5 hours, which were rather poorly established.

DISCUSSION

The most important result of this investigation was the indication that the variations in strength of N-155 sheet at 1600°F as a result of cold work and annealing during fabrication would be small. The variations observed were generally less than the normal heat-to-heat variation for N-155 sheet.

In cold forming parts from sheet there will necessarily be a range in reduction from no deformation to the maximum. In this investigation the heat treatments used generally reduced strength at 1600°F of the sheet which received no cold work. The result was lower or no higher strength values for material with no cold work than for cold worked material. The one study of the effect of percent cold deformation indicated that strengths first increase and then fall off with increasing deformation. The relatively small variations in strength of material cold reduced 8-percent and then heat treated under several conditions suggests that this was probably quite general for the heat treatments considered. This then indicated that within the rather small range of variations in strength observed, the best treatment would be the one which results in the least loss in strength of the undeformed base metal.

There were two treatments which came nearest to meeting this requirement:

1. Water quenching from 2100°F,

2. Furnace cooling from 2100°F and reheating to 1650°F.

The second treatment had the further advantage that it avoided reductions in ductility in the rupture tests at 1600°F for cold worked material and considerable increased it for the undeformed base material.

There are a number of limitations to these indicated principles for cold working and annealing during fabrication:

1. Considerations of cost, ease of forming to necessary dimensional control, warpage during heat treatment, surface preservation and other practical considerations would control the heat treatment used after cold forming within the range of heat treatments considered since the effects on properties were so small. The only possible exception would be the lowered ductility in the rupture tests for certain reductions and heat treatments.

2. The generalities are based on one sheet. In view of known heat-to-heat variations and probable variations of initial heat treatment and properties within the specification, quite different conclusions might be reached regarding the effects of the annealing treatments during cold forming for sheets with other initial properties. The variations observed were sufficiently small that properties in the initial condition could considerably alter trends indicated by the data.

3. The inter-relationships of treatments and cold work to properties varied considerably with the time period and the measure of strength. Thus, there are particular combinations of rupture or total deformation strength for particular time periods when the results were contrary to the general trends. If service conditions should be similar to these exceptions, the most favorable treatment might be different than is indicated by general trends.

Metallurgical Considerations

A fairly extensive study of the influence of working conditions on the response of N-155 alloy to heat treatment (ref. 2) indicated that the properties of N-155 alloy were relatively independent of prior history for any specific heat treatment. It was recognized, however, that this conclusion was based on conditions of heat treatments which attained near equilibrum structures for the treatments. The 10-minute treatments at 2100°F were probably too short in duration to meet this requirement and some of the variations observed were due to variation of structural change attained as influenced by prior history. Possibly more than 8-percent reduction was necessary to induce recrystallization during heating. The 10-minute period of heating would also be short for solution and diffusion of precipitates.

2. It should be recognized, however, that the conclusion of Reference 2 regarding independence of properties from prior history effects for a given heat treatment actually involved ranges in strength similar to those found for the sheet in this investigation. Thus, changing temperatures of heat treatment are considerably more influential than the prior history effects.

3. No microstructural studies were conducted. There is, however, a definite possibility that the particular conditions of working and heat treatment could have caused exaggerated grain growth when the reduction per pass was small. All alloys are subject to abnormal grain growth when deformed a critical

small amount and then reheated to temperatures sufficiently high for grain growth to occur. The critical deformation is usually between 0.5 and 2.0 percent. A temperature of 2100°F should be sufficiently high for abnormal grain growth, although the ten minute heating periods may have been too short. It is also possible that the critical deformation was missed in the reductions studied. It is known that repeated critical deformation and heating greatly increases abnormal grain growth. It would seem desirable to determine if abnormal grain growth did occur but had little influence on properties at 1600°F, or if it was missed by chance due to the particular reductions considered. If abnormal grain growth were inevitable where a range of reductions occur and it should be detrimental to properties at 1600°F as it often is at other temperatures, it would be well to know it.

CONCLUSIONS

The variations in rupture and total-deformation strength at 1600°F found for cold reduced and annealed N-155 sheet were relatively small. The variations were generally less than 1000 to 2000 psi. These variations are no more and generally less than the normally expected heat-to-heat variations for the alloy in sheet form. The annealing treatments were restricted to 2100°F with or without subsequent heating to 1850° or 1650°F. Some loss in ductility in rupture tests at 1600°F was associated with cold reduction and annealing at 2100°F unless the subsequent treatment at 1650°F was also used.

The treatments used reduced the strength of the undeformed sheet as much or more than the cold worked conditions. The results suggest, therefore, two possible generalities regarding heat treatment after cold fabrication of N-155 sheet.

1. In view of the relatively small effect of prior cold work on properties after annealing, practical considerations of cost and production ease should control the annealing treatment.

2. Within the limitation of the previous paragraph, better retention of properties over the range of reductions involved in cold forming operations can probably be obtained by using the heat treatment which reduces the strength of undeformed sheet material the least.

A number of limitations of these two conclusions are present in the report and should be considered in any practical case.

REFERENCES

1. "The Stress-Rupture Properties at 1650°F of N-155 Material in Sheet Form" K. P. MacKay and J. W. Freeman, Report 2536-8-P.

2. "Influence of Hot-Working Conditions on High-Temperature Properties of a Heat-Resistant Alloy" J. F. Ewing and J. W. Freeman, National Advisory Committee for Aeronautics, Technical Note 3727.

Table I

Cold Working and Annealing Treatments Used for Sheet Specimens of N-155 Alloy

Specimen Code	Cold Reduction by Rolling per pass (%)	Number of passes	Total Reduction (%)
As-received (AMS 5532)			
E4B	-	-	0
Preheat 1450°F, 5 min. - Heat 2100°F, H_2 atmosphere, 10 min. - Water Quench			
C4F	-	-	0
C4E	2	4	8
Preheat 1450°F, 5 min. - Heat 2100°F, H_2 atmosphere, 10 min. - Furnace cool to 200°F			
B4B	-	-	0
B4A	1	4	4
C4A	2	4	8
D4A	4	4	16
E4A	6	4	24
Preheat 1450°F, 5 min. - Heat 2100°F, H_2 atmosphere, 10 min. - Furnace cool to 200°F - Heat 1850°F, DNH_3 atmosphere, 10 min. - Furnace cool			
D4B	-	-	0
C4C	2	4	8
Preheat 1450°F, 5 min. - Heat 2100°F, H_2 atmosphere, 10 min. - Furnace cool to 200°F - Heat 1650°F, 2 hours - Air cool			
C4B	-	-	0
C4D	2	4	8

Table II

Stress-Rupture and Stress-Total Deformation Data Obtained at 1600°F for Sheet Specimens of N-155 Alloy after Cold Working and Annealing

Spec. No.	Def. Per pass (%)	No. of passes	Total Def. (%)	Stress (psi)	Rupture Time (hrs)	Elong. (%)	Deformation on Loading (%)	Time for Specified Total Deformation (hours)			
								0.2%	0.5%	1.0%	2.0%
As Received											
E4B1	-	-	0	14,500	27.5	21.0	0.110	0.5	2.9	5.4	9.2
2	-	-	0	12,000	66.9	20.0(1)	0.083	1.3	7.7	16.0	(25)
3	-	-	0	9,000	402.9	8.5	0.052	20.0	74.0	137.	223
Preheat 1450°F, 5 min. - Heat 2100°F, H_2 atmosphere, 10 min. - Water Quench											
C4F1	-	-	0	14,500	19.2	20.0(1)	0.104	0.2	0.8	1.8	(4.0)
2	-	-	0	11,500	114.4	15.0(1)	0.709	1.6	11.5	25.5	41.9
3	-	-	0	9,400	133.3	13.0	0.062	6.3	20.2	37.8	(60)
C4E1	2	4	8	14,500	23.2	33.5	0.096	0.2	0.6	1.3	4.0
2	2	4	8	11,500	167.4	8.5	0.078	3.8	28.8	60.3	106.
3	2	4	8	9,400	350.1	5.0	0.065	13.5	70.0	162.	273.
Preheat 1450°F, 5 min. - Heat 2100°F, H_2 atmosphere, 10 min. - Furnace cool to 200°F											
B4B2	-	-	0	12,000	47.0	18.0(1)	0.090	0.9	2.5	5.7	11.6
3	-	-	0	9,800	179.9	15.5(1)	0.063	6.0	15.0	34.5	63.0
1	-	-	0	8,700	290.5	10.5	0.057	10.7	35.5	74.5	134.7
B4A1	1	4	4	14,500	22.4	17.0(1)	0.107	0.7	2.9	6.6	9.8
2	1	4	4	11,500	113.8	16.0	0.081	1.3	7.7	19.2	34.6
3	1	4	4	9,400	332.5	10.0	0.052	12.0	43.0	101.	178.
C4A1	2	4	8	14,500	26.4	16.5	0.106	0.5	1.8	4.2	(9.1)
2	2	4	8	11,500	104.0	12.0	0.085	1.1	7.6	27.7	44.4
3	2	4	8	9,400	250.4	7.0	0.072	12.0	38.0	105.	183.
D4A2	4	4	16	11,500	37.6	10.5	0.086	0.15	2.65	7.1	14.4
1	4	4	16	9,400	166.9	9.5	0.065	6.2	19.5	47.0	80.5
3	4	4	16	9,150	188.5	10.5	0.061	3.25	14.5	35.5	71.5

Table II (continued)

Spec. No.	Def. Per pass (%)	No. of passes	Total Def. (%)	Stress (psi)	Rupture Time (hrs)	Elong. (%)	Deformation on Loading (%)	Time for Specified Total Deformation (hours) 0.2%	0.5%	1.0%	2.0%
E4A2	6	4	24	11,500	44.4	13.5(1)	0.085	0.8	3.0	6.8	13.5
	6	4	24	9,000	192.4	8.5(1)	0.068	6.5	22.0	47.0	86.
	6	4	24	8,000	369.9	8.0	0.060	13.0	50.	109.	199.
Preheat 1450°F, 5 min. - Heat 2100°F H_2 atmosphere., 10 min. - Furnace Cool - Heat 1850°F, DNH_3 atmosphere, 10 min - Furnace Cool											
D4B2	-	-	0	14,500	15.8	40.5	0.108	0.12	0.45	1.0	2.15
1	-	-	0	11,500	94.5	39.0	0.084	0.65	2.35	7.0	14.9
3	-	-	0	9,400	268.6	12.5	0.066	6.5	19.0	41.5	85.5
C4C2	2	4	8	14,500	16.0	35.5	0.132	0.1	0.55	1.3	2.7
1	2	4	8	11,500	74.5	13.9	0.090	0.5	4.0	12.1	24.4
3	2	4	8	9,400	416.6	10.0(1)	0.070	11.0	47.0	127.	232.0
Preheat 1450°F, 5 min. - Heat 2100°F, H_2 atmosphere, 10 min. - Furnace cool to 200°F - Heat 1650°F, 2 hrs. - Air Cool											
C4B1	-	-	0	14,500	24.9	60.	0.095	0.1	0.4	0.8	(2.6)
2	-	-	0	11,500	87.4	41.5	0.080	0.5	1.9	5.1	11.4
3	-	-	0	9,400	384.5	23.5	0.070	5.0	17.5	38.5	84.0
C4D1	2	4	8	14,500	31.7	36.5	0.101	0.2	1.0	2.2	4.3
2	2	4	8	11,500	128.4	18.0(2)	0.098	1.3	7.6	26.0	50.7
3	2	4	8	9,400	366.2	9.5(1)	0.093	10.0	54.0	134.0	222.0

(1) Broken in gage mark
(2) Broken outside gage mark

Table III

Rupture and Total Deformation Strengths for Specified Time Periods at 1600°F for N-155 Sheet Material after Indicated Cold Working and Annealing Treatments

Heat Treatment	Code	Reduction (%)	Rupture Strength for Specified Time Periods (hours) 20	80	300
As Received (AMS 5532)	E4B	0	15,000	12,000	9,600
Preheat 1450°F, 5min.	C4F	0	14,500	11,250	8,800
Heat 2100°F, H_2 atmosphere, 10 min.	C4E	8	14,800	12,500	9,800
Water Quench					
Preheat 1450°F, 5 min.	B4B	0	13,500	11,000	8,600
Heat 2100°F, H_2 atmosphere, 10 min.	B4A	4	15,100	12,000	9,600
Furnace cool to 200°F	C4A	8	15,200	12,100	9,000
	D4A	16	12,500	10,200	8,500
	E4A	24	13,200	10,300	8,300
Preheat 1450°F, 5 min.	D4B	0	14,000	11,800	9,200
Heat 2100°F, H_2 atmosphere, 10 min.	C4C	8	13,900	11,800	9,800
Furnace cool to 200°F					
Heat 1850°F, DNH_3 atmosphere 10 min.					
Furnace cool					
Preheat 1450°F, 5 min.	C4B	0	14,900	12,000	9,800
Heat 2100°F, H_2 atmosphere, 10 min.	C4D	8	16,000	12,500	9,800
Furnace cool to 200°F					
Heat 1650°F, 2 hrs.					
Air cool					

Table III (continued)

Heat Treatment	Code	Reduction (%)	2% Total Deformation Strength for Specified Time Periods (hours)			
			5	20	80	300
As Received	E4B	0	(15,400)	12,800	10,400	8,600
Preheat 1450°F, 5 min.	C4F	0	14,200	11,900	10,000	8,400
Heat 2100°F, H_2 atmosphere, 10 min.	C4E	8	14,300	13,000	11,800	9,200
Water Quench						
Preheat 1450°F, 5 min.	B4B	0	(13,500)	11,200	9,400	7,600
Heat 2100°F, H_2 atmosphere, 10 min.	B4A	4	(15,500)	12,700	10,500	8,700
Furnace cool to 200°F	C4A	8	(15,800)	13,000	10,500	8,800
	D4A	16	(13,000)	11,000	9,400	8,000
	E4A	24	(13,200)	11,000	9,100	7,600
Preheat 1450°F, 5 min.	D4B	0	13,200	11,200	9,500	8,200
Heat 2100°F, H_2 atmosphere, 10 min.,	C4C	8	13,600	11,900	10,300	9,100
Furnace cool						
Heat 1850°F, DNH_3 atmosphere, 10 min.						
Furnace Cool						
Preheat 1450°F, 5 min.	C4B	0	13,000	11,100	9,500	8,200
Heat 2100°F, H_2 atmosphere, 10 min.	C4D	8	14,300	12,500	10,800	9,000
Furnace cool to 200°F,						
Heat 1650°F, 2 hrs.						
Air cool						

Table III (continued)

Heat Treatment	Code	Reduction (%)	1% Total Deformation Strength for Specified Time Periods (hours) 5	20	80	300
As Received	E4B	0	14,500	11,900	9,700	8,000
Preheat 1450°F, 5 min.,	C4F	0	13,000	11,000	9,400	(8,100)
Heat 2100°F, H_2 atmosphere, 10 min.	C4E	8	12,400	12,300	11,000	8,200
Water Quench						
Preheat 1450°F, 5 min.,	B4B	0	12,400	10,300	8,600	(6,900)
Heat 2100°F, H_2 atmosphere, 10 min.	B4A	4	14,300	11,800	9,700	8,000
Furnace cool to 200°F	C4A	8	14,700	12,000	9,800	8,100
	D4A	16	12,000	10,100	8,700	7,500
	E4A	24	12,000	10,000	8,400	7,000
Preheat 1450°F, 5 min.	D4B	0	12,000	10,200	8,800	(7,700)
Heat 2100°F, H_2 atmosphere, 10 min.	C4C	8	12,500	11,000	9,800	8,600
Furnace cool						
Heat 1850°F, DNH_3 atmosphere, 10 min.						
Furnace cool						
Preheat 1450°F, 5 min.	C4B	0	11,900	10,100	8,700	(7,600)
Heat 2100°F, H_2 atmosphere, 10 min.	C4D	8	13,400	11,800	10,000	8,500
Furnace cool to 200°F						
Heat 1650°F, 2 hrs.						
Air Cool						

Table III (continued)

Heat Treatment	Code	Reduction (%)	0.5% Total Deformation Strength for Specified Time Period (hours) 5	20	80	300
As Received	E4B	0	13,000	10,800	9,000	(7,500)
Preheat 1450°F, 5 min.,	C4F	0	11,800	10,000	8,600	(7,400)
Heat 2100°F, H_2 atmosphere, 10 min.	C4E	8	(12,800)	11,700	9,100	(6,900)
Water Quench						
Preheat 1450°F, 5 min.	B4B	0	11,000	9,400	7,600	(6,200)
Heat 2100°F, H_2 atmosphere, 10 min.	B4A	4	12,900	10,300	8,600	(7,000)
Furnace Cool to 200°F	C4A	8	12,300	10,300	8,500	(7,000)
	D4A	16	10,800	9,100	7,700	(6,600)
	E4A	24	10,800	9,100	7,500	(6,300)
Preheat 1450°F, 5 min.	D4B	0	10,700	9,300	(8,200)	(7,200)
Heat 2100°F, H_2 atmosphere, 10 min.	C4C	8	11,200	10,100	9,000	(8,000)
Furnace cool						
Heat 1850°F, DNH_3 atmosphere, 10 min.						
Furnace cool						
Preheat 1450°F, 5 min.	C4B	0	10,600	9,300	(8,100)	(7,200)
Heat 2100°F, H_2 atmosphere, 10 min.	C4D	8	12,000	10,300	9,000	(7,900)
Furnace cool to 200°F						
Heat 1650°F, 2 hrs.						
Air cool						

Table III (continued)

Heat Treatment	Code	Reduction (%)	0.2% Total Deformation Strength for Specified Time Period (hours)			
			5	20	80	300
As Received	E4B	0	10,500	9,000	7,800	(6,700)
Preheat 1450°F, 5 min.	C4F	0	10,100	8,900	7,700	(6,700)
Heat 2100°F, H_2 atmosphere, 10 min.	C4E	8	11,300	8,700	(6,700)	(5,200)
Water Quench						
Preheat 1450°F, 5 min.	B4B	0	9,900	8,200	6,500	
Heat 2100°F, H_2 atmosphere, 10 min.	B4A	4	10,400	8,800	7,300	
Furnace cool to 200°F	C4A	8	10,400	8,900	7,600	
	D4A	16	(9,300)	(7,900)	6,700	
	E4A	24	9,200	7,600	6,300	
Preheat 1450°F, 5 min.	D4B	0	9,600	8,500	(7,600)	
Heat 2100°F, H_2 atmosphere, 10 min.	D4C	8	10.000	9,000	(8,000)	
Furnace cool						
Heat 1850°F, DNH_3 atmosphere, 10 min.						
Furnace cool						
Preheat 1450°F, 5 min.	C4B	0	9,500	(8,300)	(7,300)	
Heat 2100°F, H_2 atmosphere, 10 min.	C4D	8	10,000	8,900	(7,900)	
Furnace cool to 200°F						
Heat 1650°F, 2 hrs.						
Air cool						

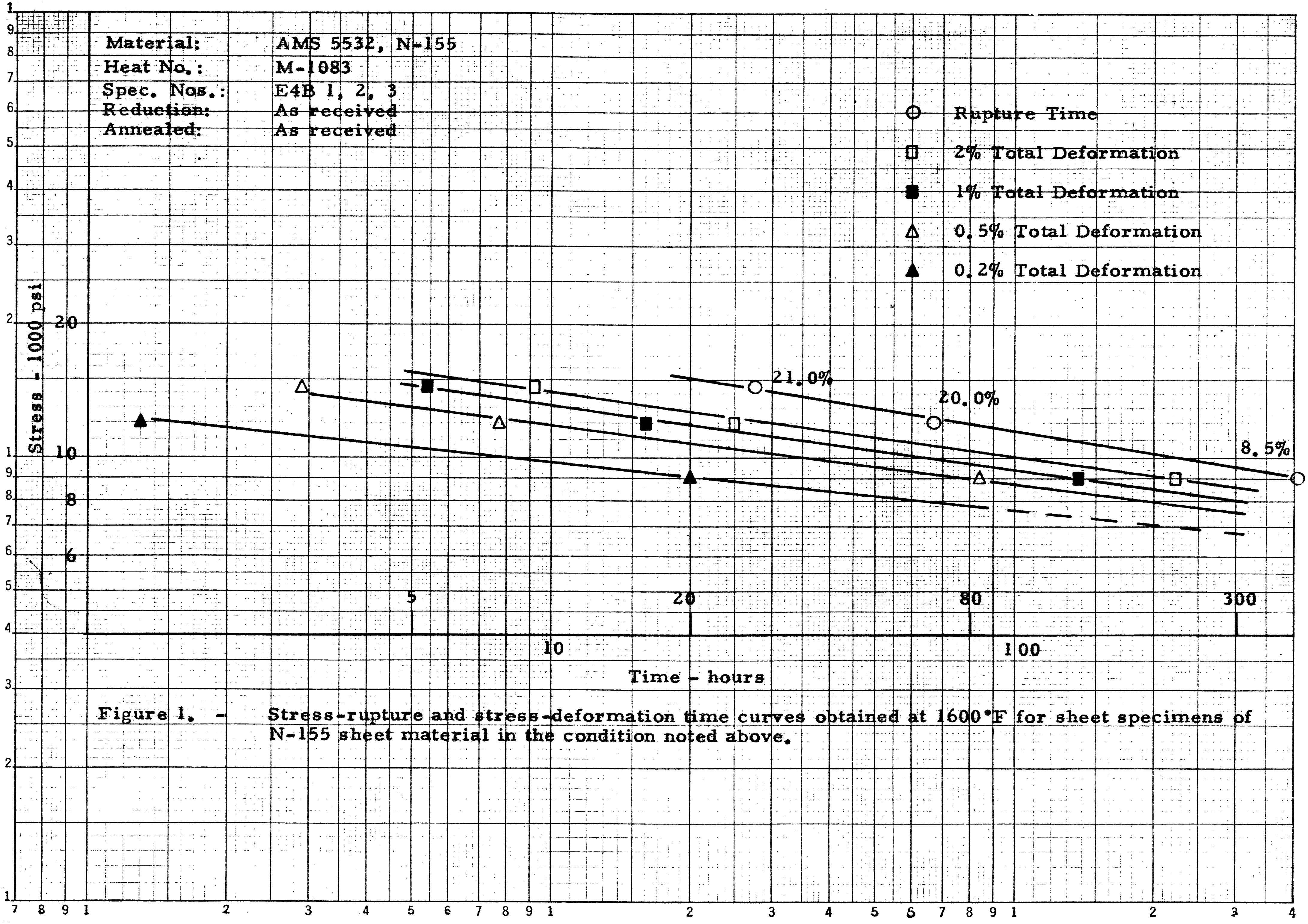

Figure 1. - Stress-rupture and stress-deformation time curves obtained at 1600°F for sheet specimens of N-155 sheet material in the condition noted above.

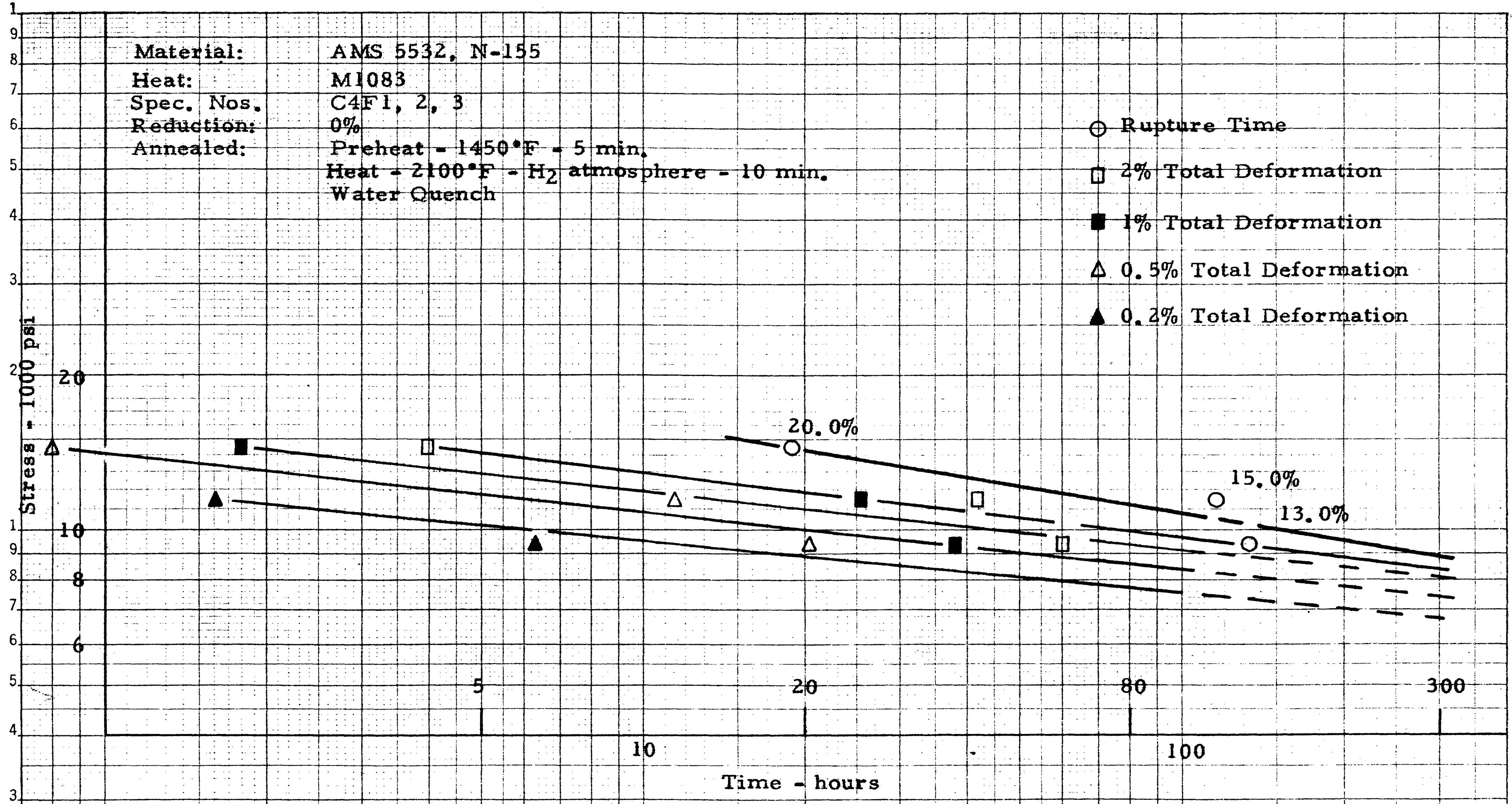

Figure 2. - Stress-rupture and stress-total deformation time curves obtained at 1600°F from sheet specimens of N-155 sheet material in the condition noted above.

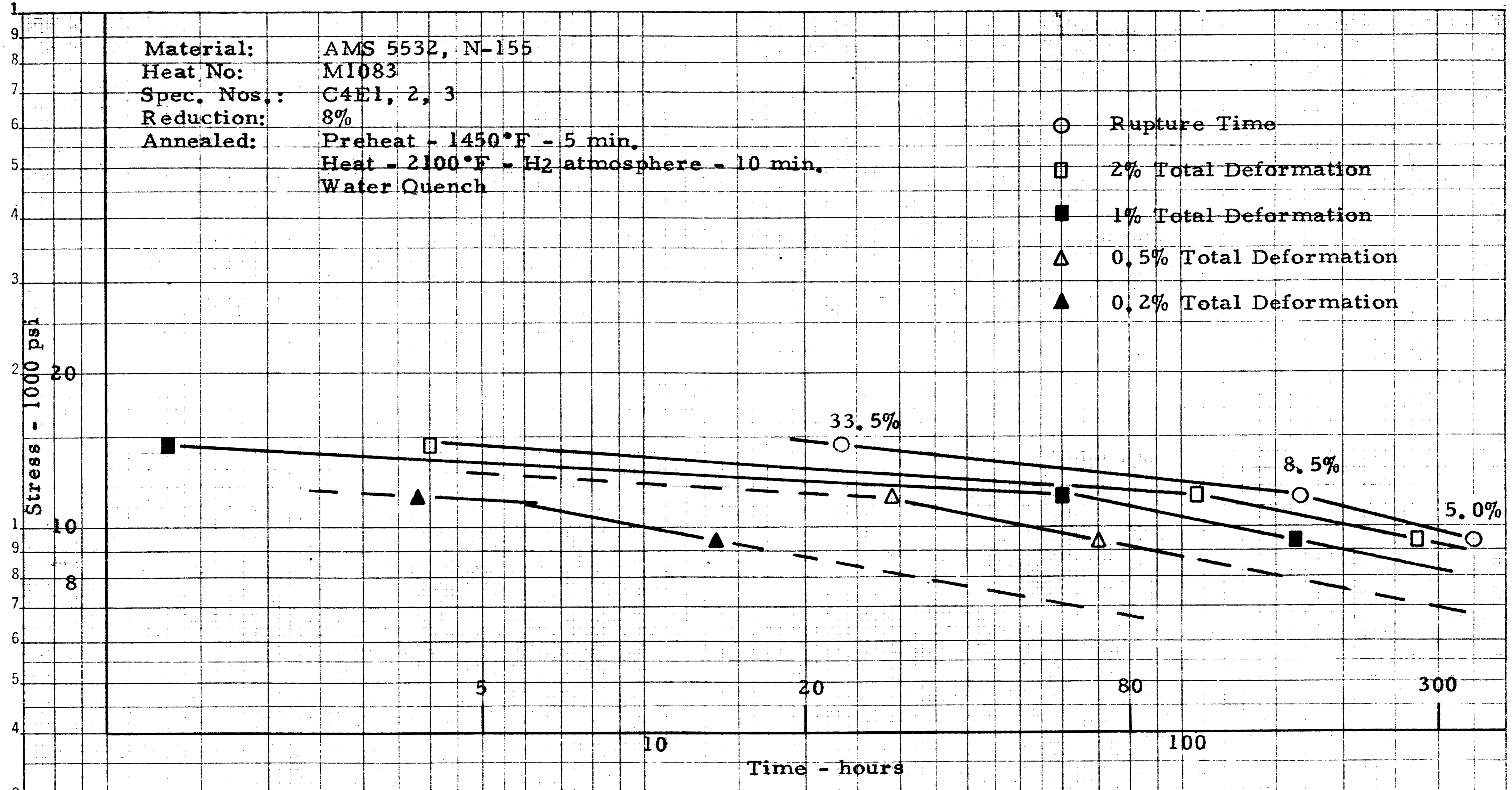

Figure 3. - Stress-rupture and stress-total deformation time curves obtained at 1600°F from sheet specimens of N-155 sheet material in the condition noted above.

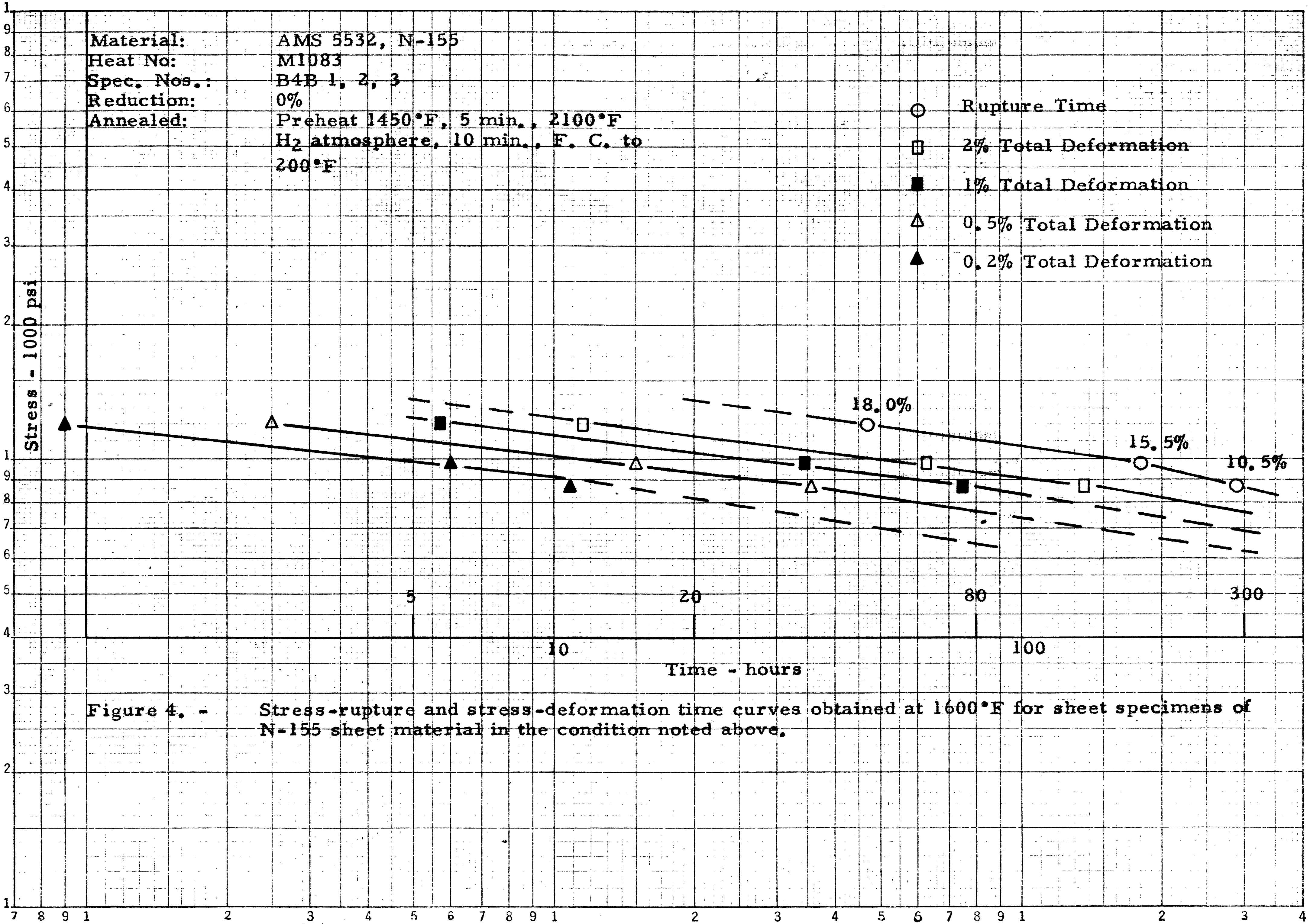

Figure 4. - Stress-rupture and stress-deformation time curves obtained at 1600°F for sheet specimens of N-155 sheet material in the condition noted above.

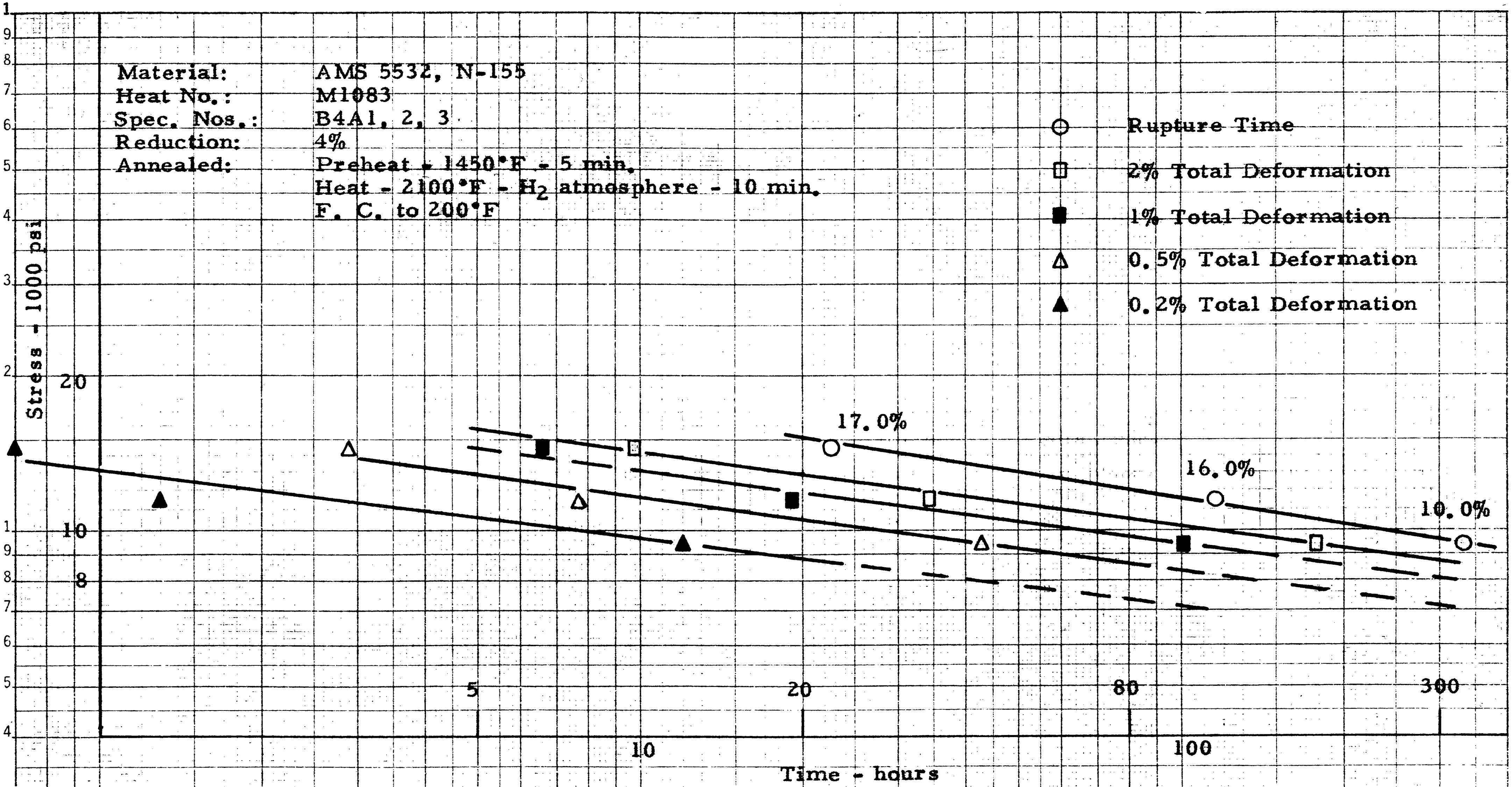

Figure 5. - Stress-rupture and stress-deformation time curves obtained at 1600°F for sheet specimens of N-155 sheet material in the condition noted above.

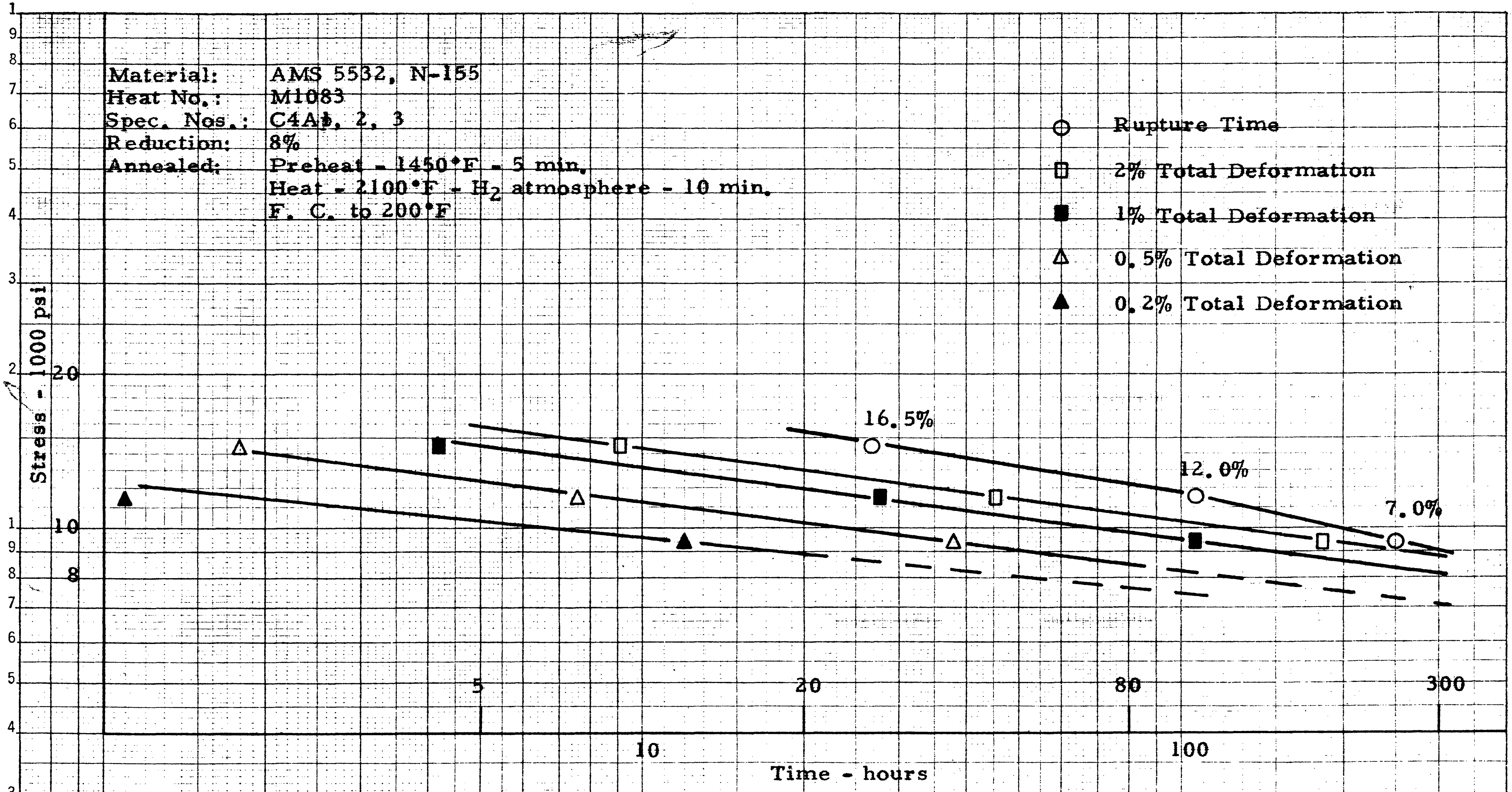

Figure 6. - Stress-rupture and stress-deformation time curves obtained at 1600°F for sheet specimens of N-155 sheet material in the condition noted above.

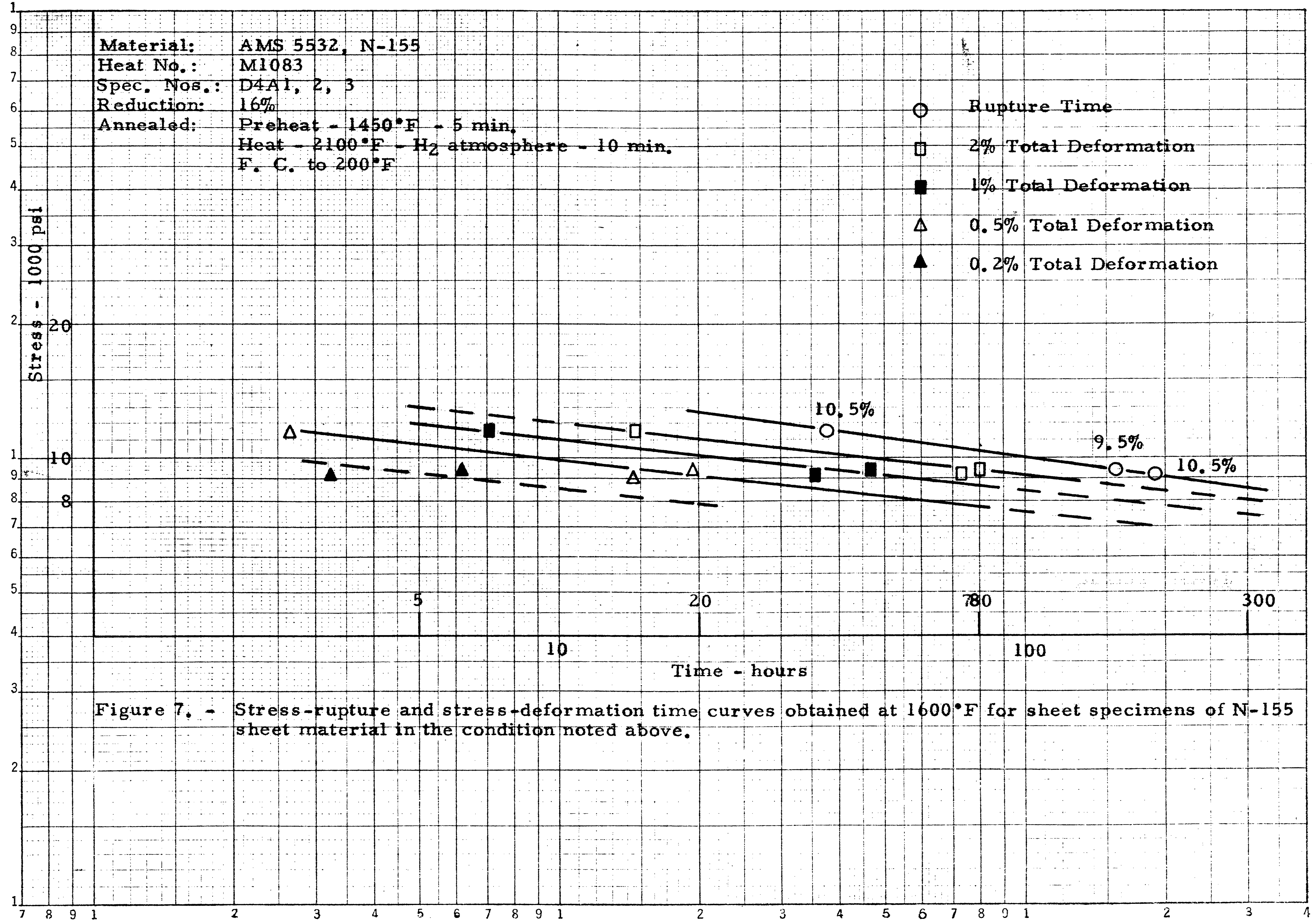

Figure 7. - Stress-rupture and stress-deformation time curves obtained at 1600°F for sheet specimens of N-155 sheet material in the condition noted above.

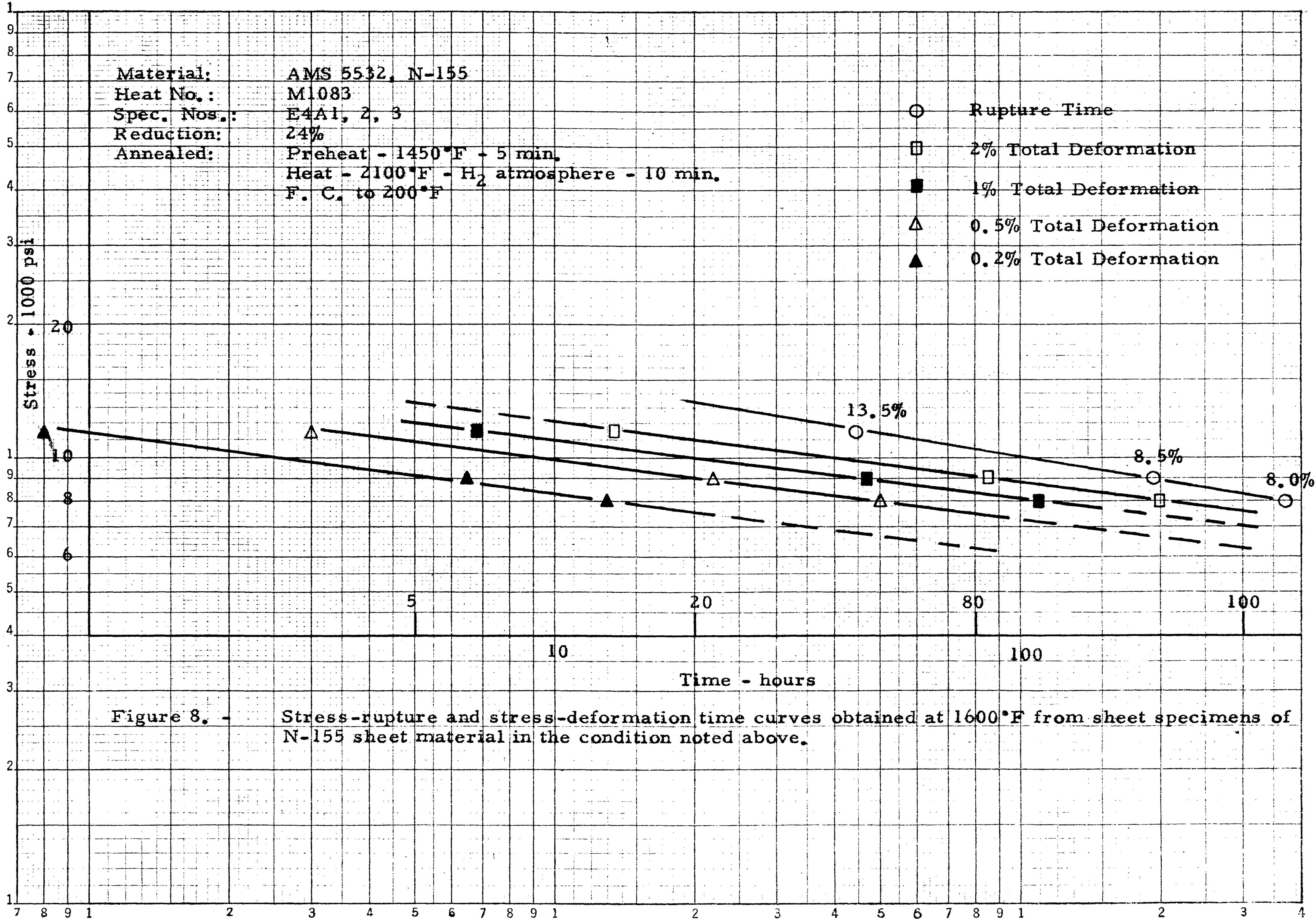

Figure 8. - Stress-rupture and stress-deformation time curves obtained at 1600°F from sheet specimens of N-155 sheet material in the condition noted above.

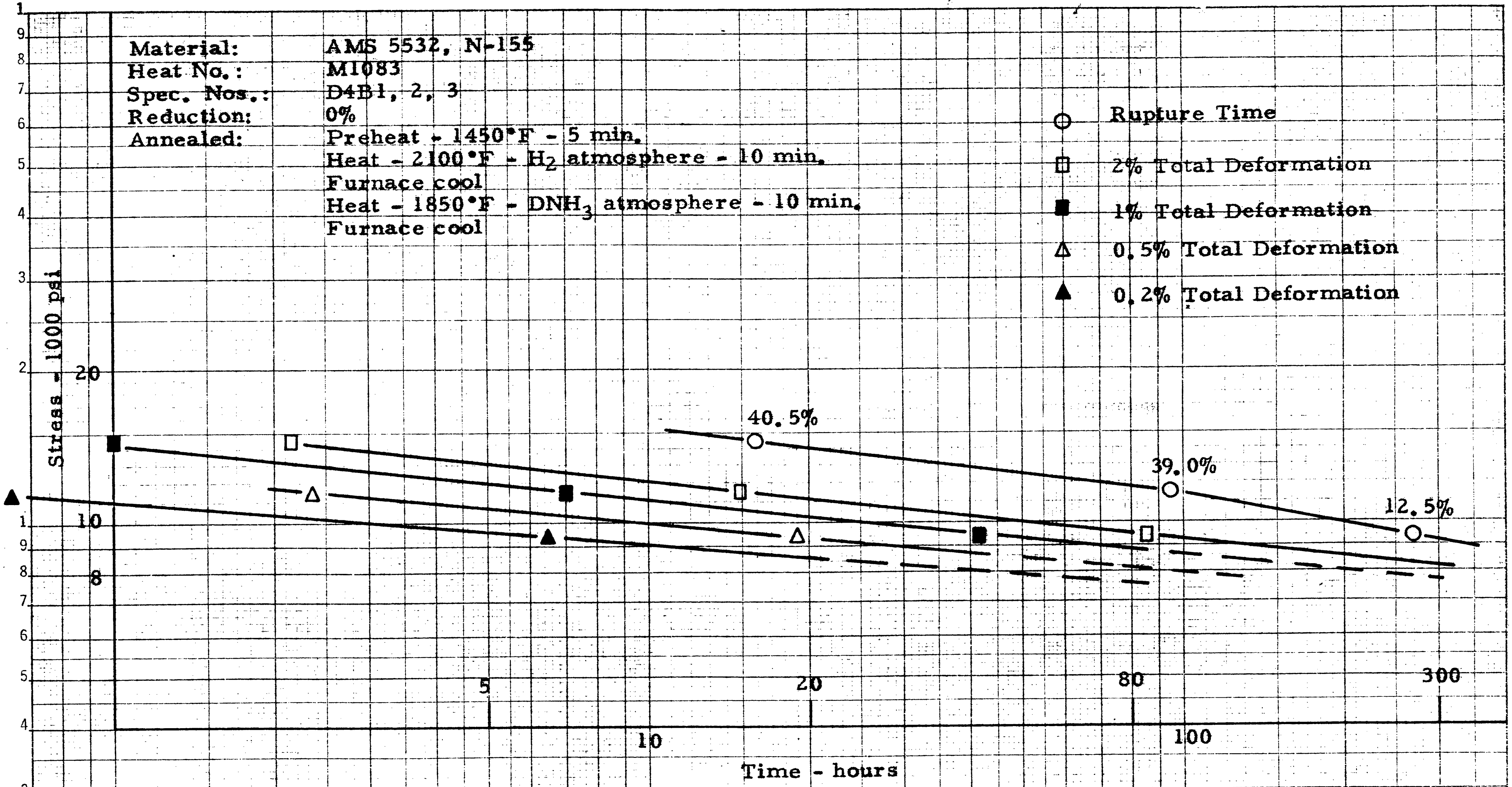

Figure 9. - Stress-rupture and stress-total deformation time curves obtained at 1600°F from sheet specimens of N-155 sheet material in the condition noted above.

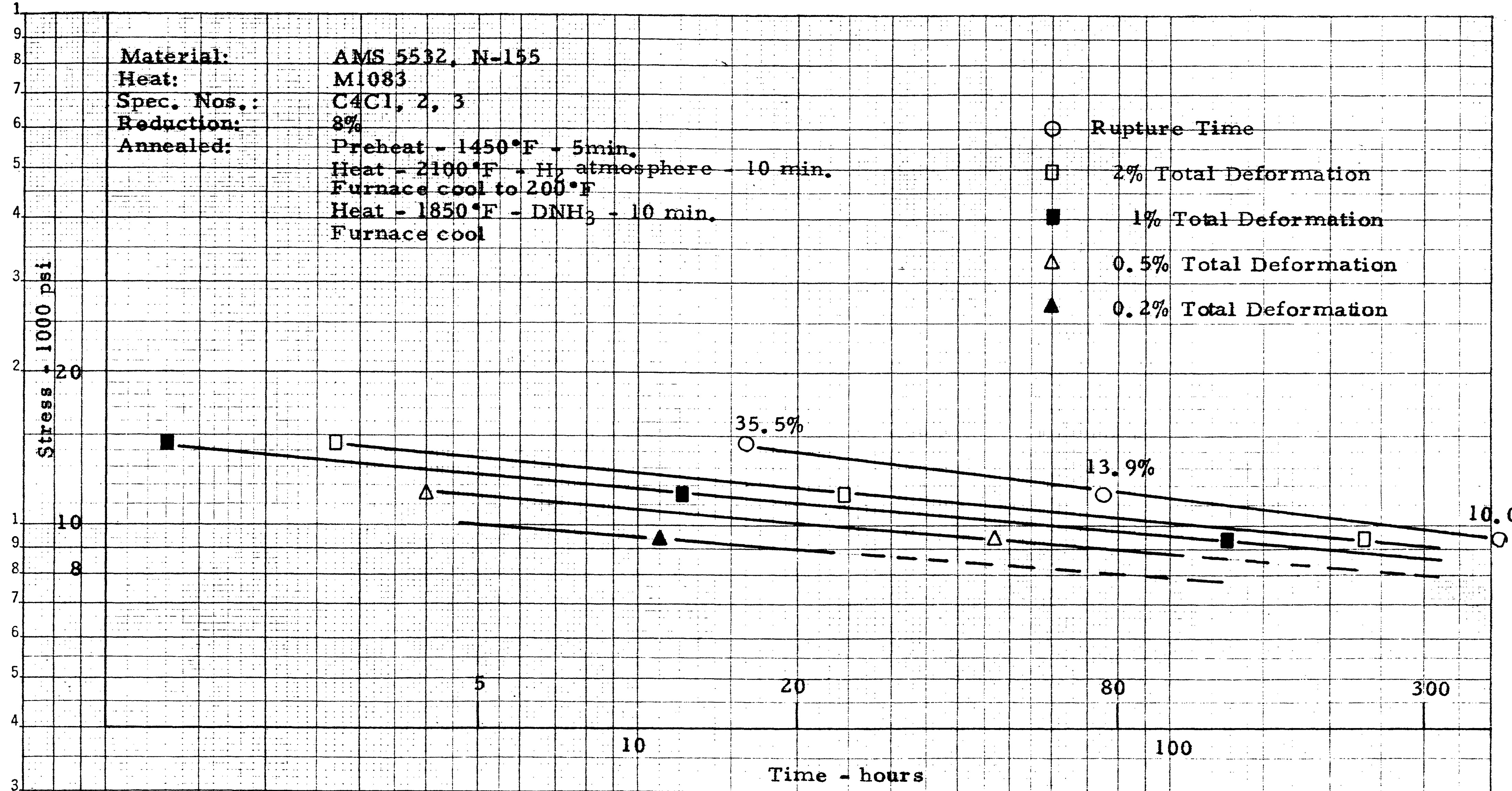

Figure 10. - Stress-rupture and stress-total deformation time curves obtained at 1600°F from sheet specimens of N-155 sheet material in the condition noted above.

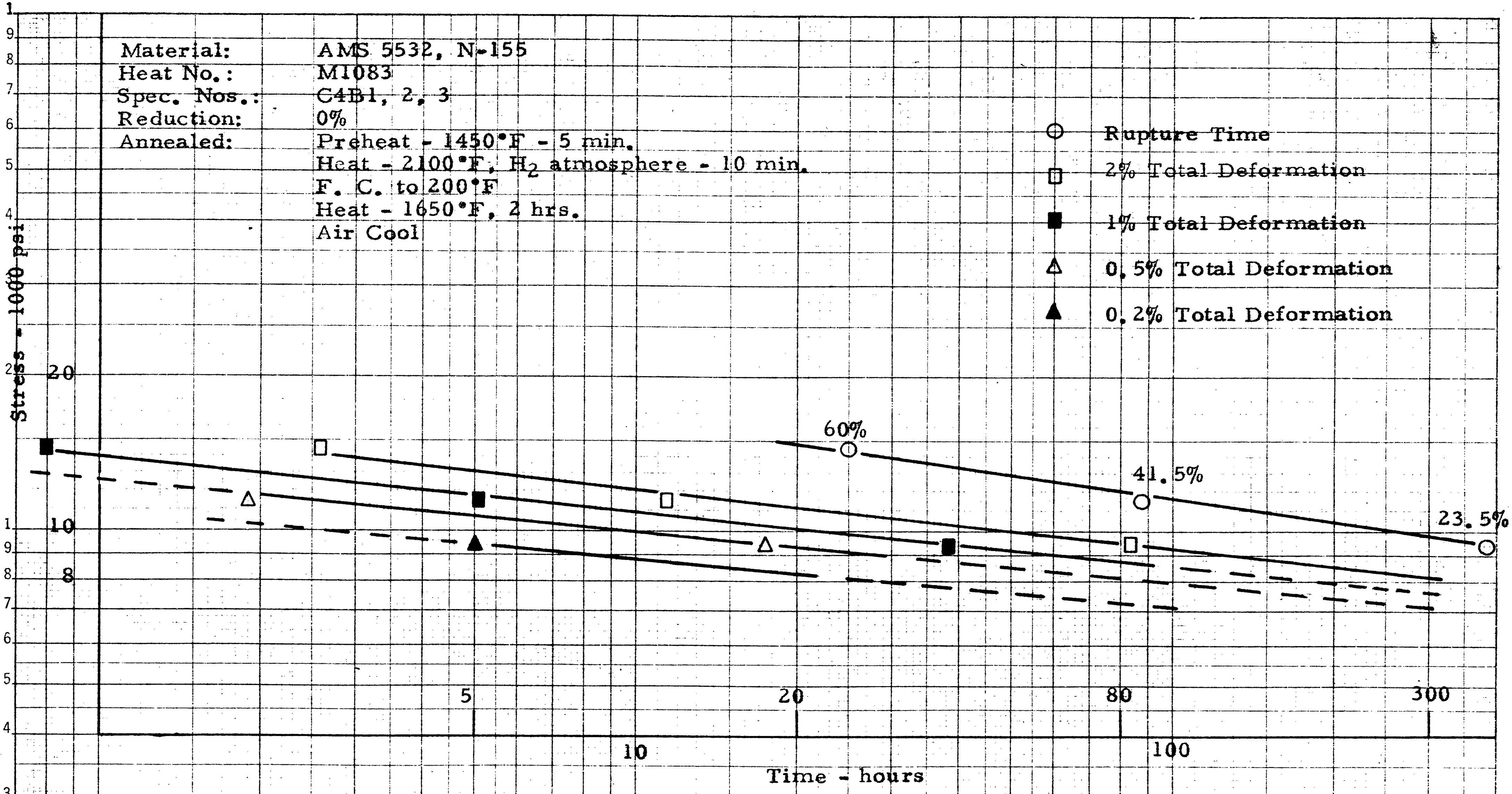

Figure 11. - Stress-rupture and stress-deformation time curves obtained at 1600°F from sheet specimens of N-155 sheet material in the condition noted above.

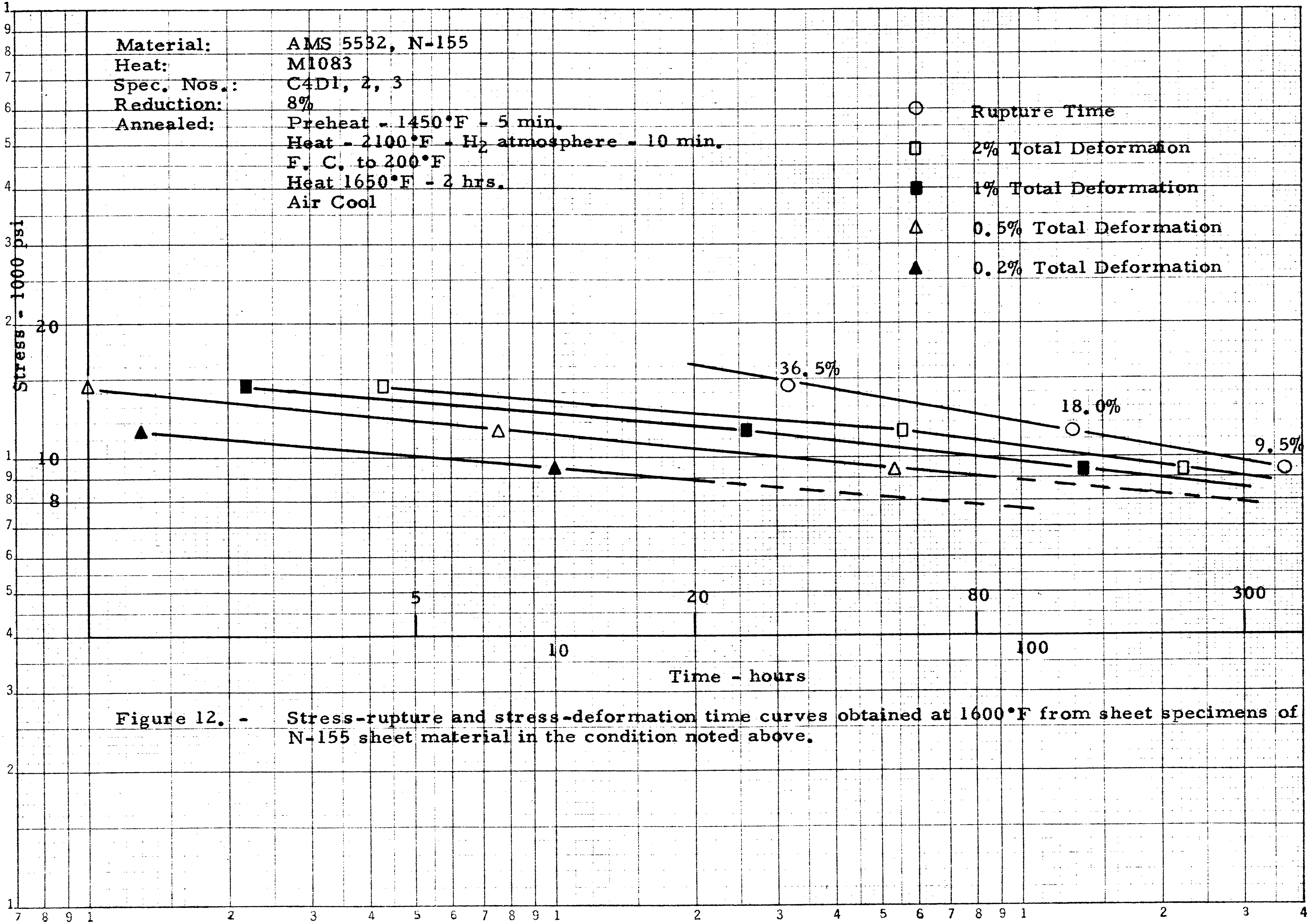

Figure 12. - Stress-rupture and stress-deformation time curves obtained at 1600°F from sheet specimens of N-155 sheet material in the condition noted above.

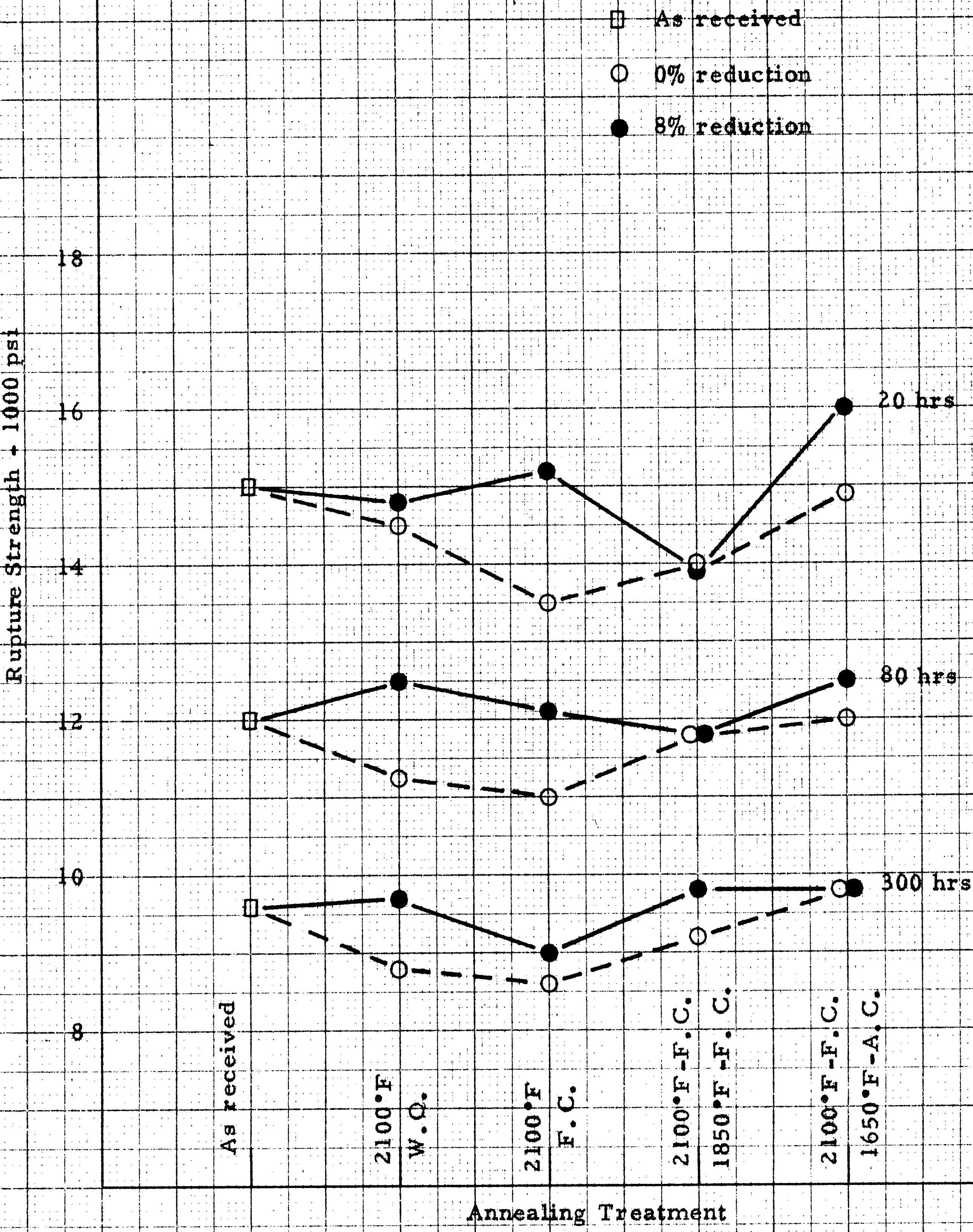

Figure 13. - Summary of the effect on rupture strength at 1600°F of various annealing treatments for N-155 sheet material after cold reductions of 0 and 8 percent.

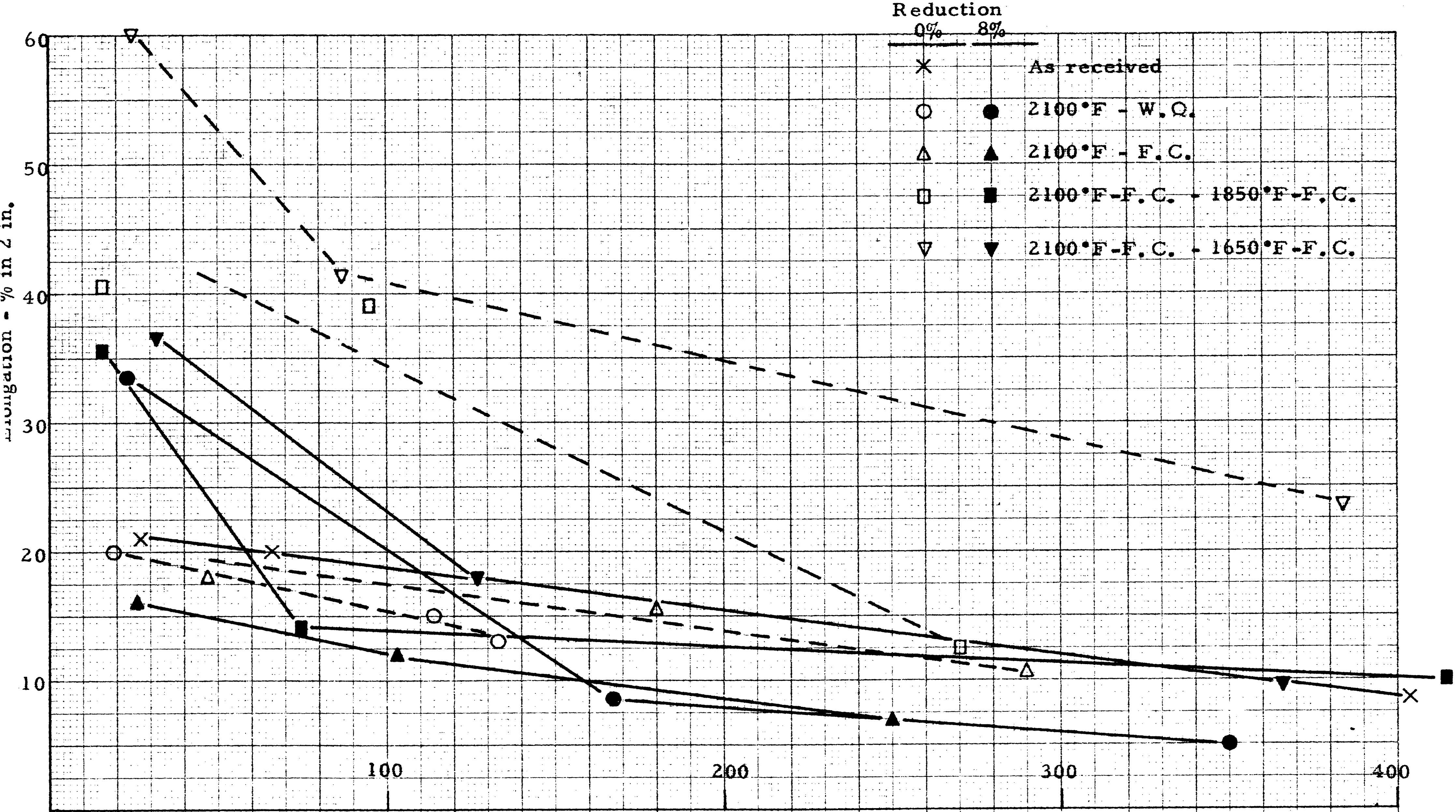

Figure 14. - Effect of various annealing treatments on elongation at rupture for various rupture times at 1600°F for N-155 sheet material after cold reductions of 0 and 8 percent.

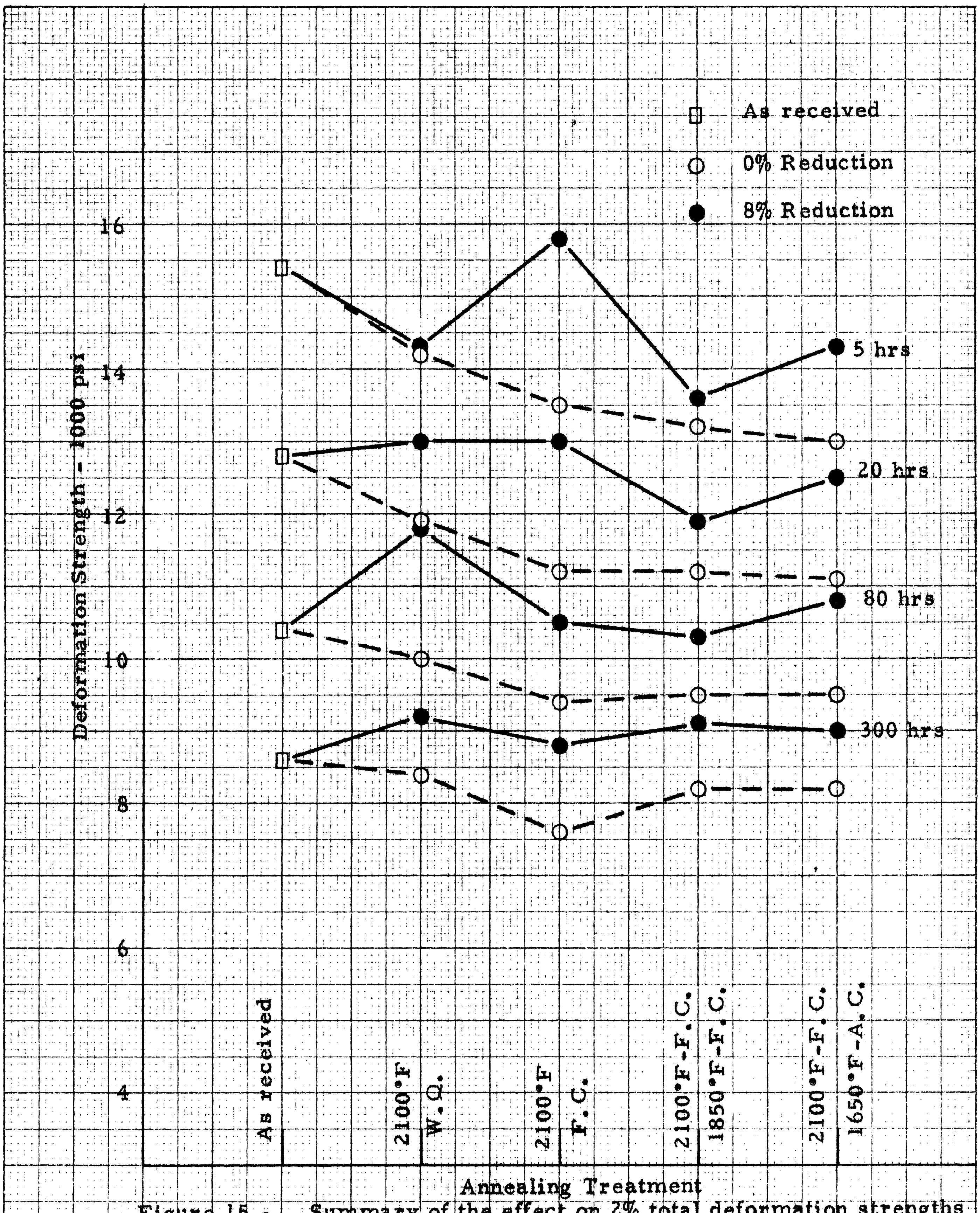

Figure 15 - Summary of the effect on 2% total deformation strengths at 1600°F of various annealing treatments for N-155 sheet material after cold reductions of 0 and 8 percent.

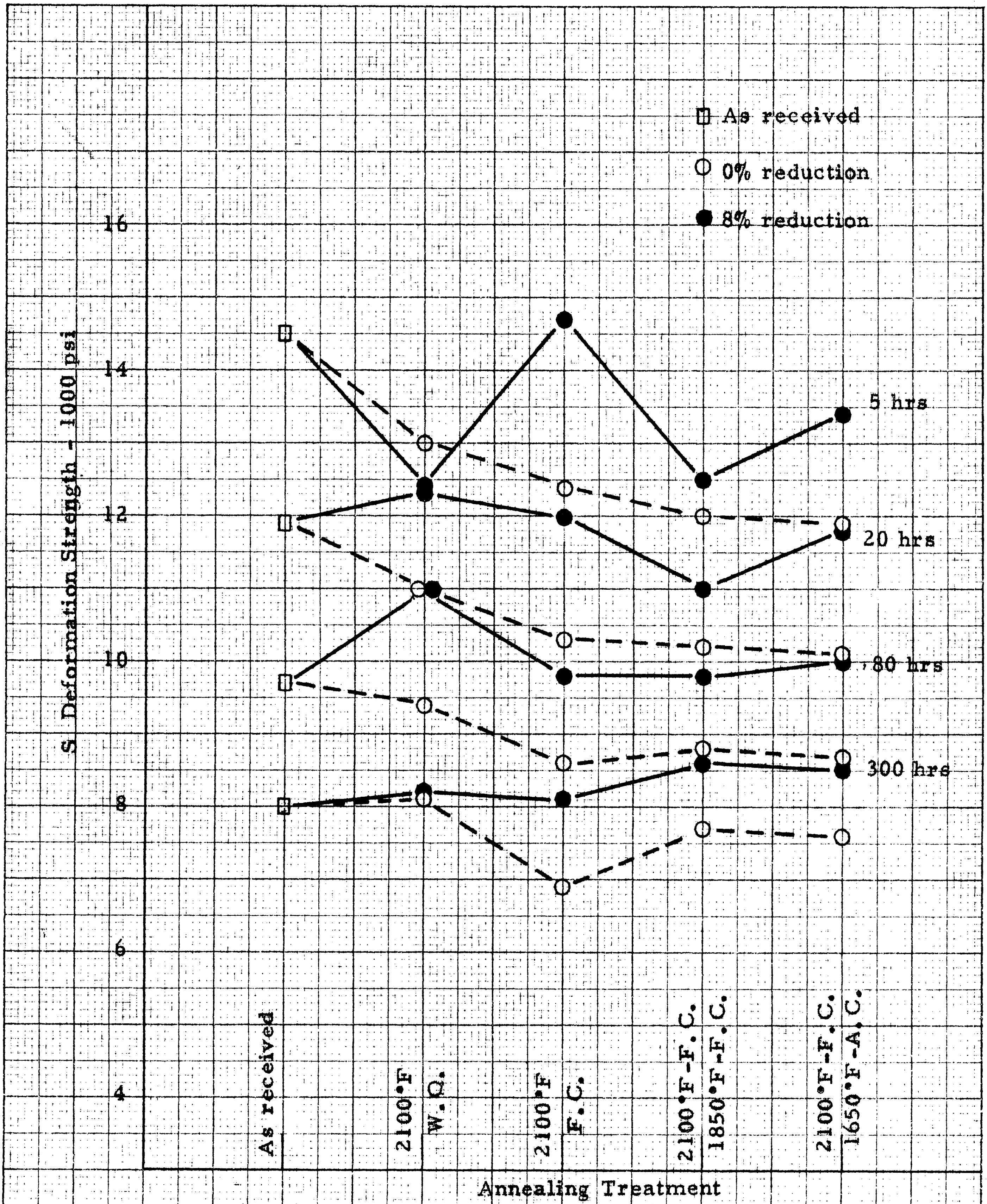

Figure 16. - Summary of the effect on 1% total deformation strengths at 1600°F of various annealing treatments for N-155 sheet material after cold reductions of 0 and 8 percent.

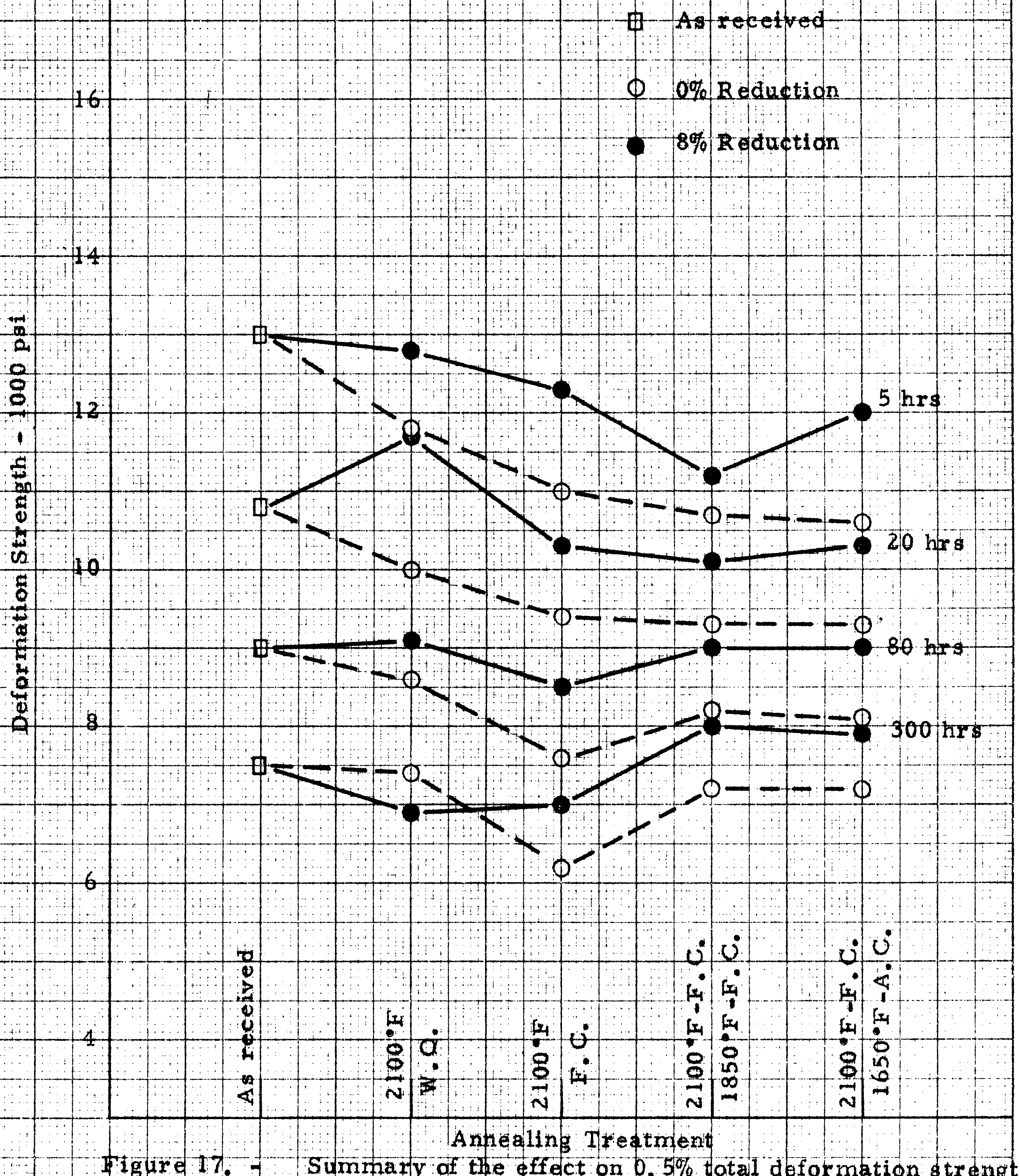

Figure 17. - Summary of the effect on 0.5% total deformation strengths at 1600°F of various annealing treatments for N-155 sheet material after cold reductions of 0 and 8 percent.

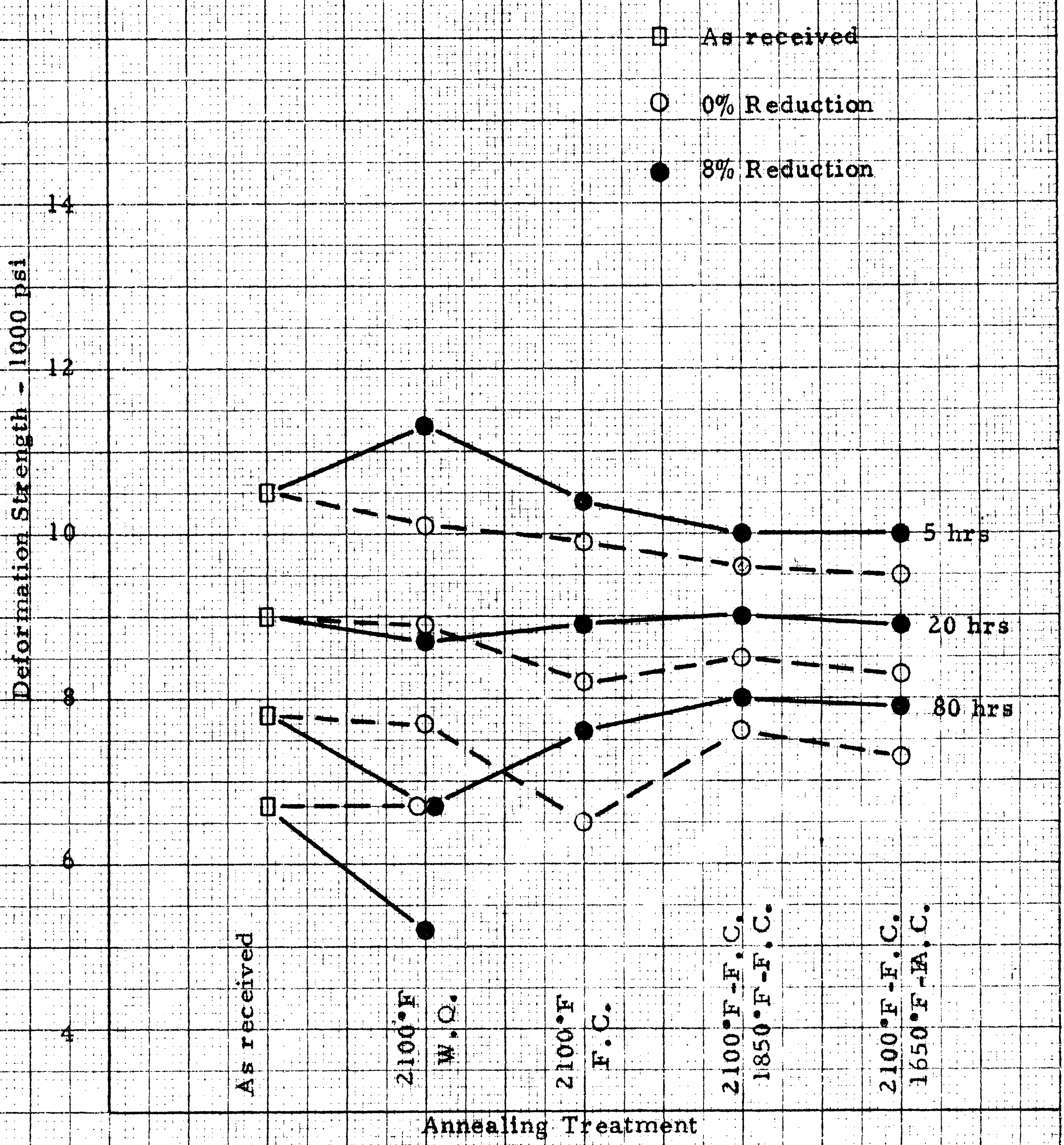

Figure 18. - Summary of the effect on 0.2% total deformation strengths at 1600°F of various annealing treatments for N-155 sheet material after cold reductions of 0 and 8 percent.

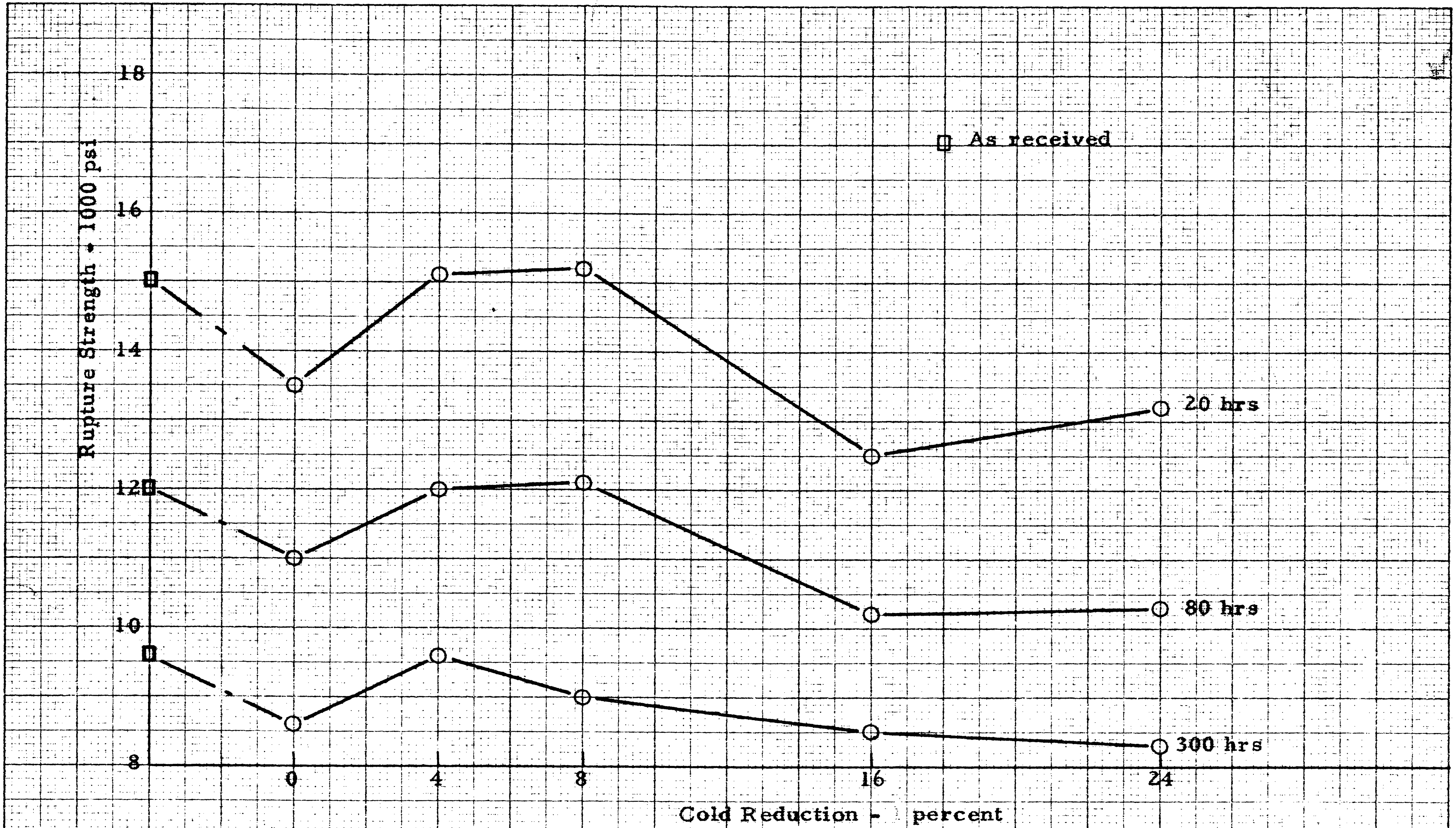

Figure 19. - Summary of the effect on rupture strength at 1600°F for N-155 sheet material of various cold reductions followed by furnace cooling from 2100°F in hydrogen atmosphere.

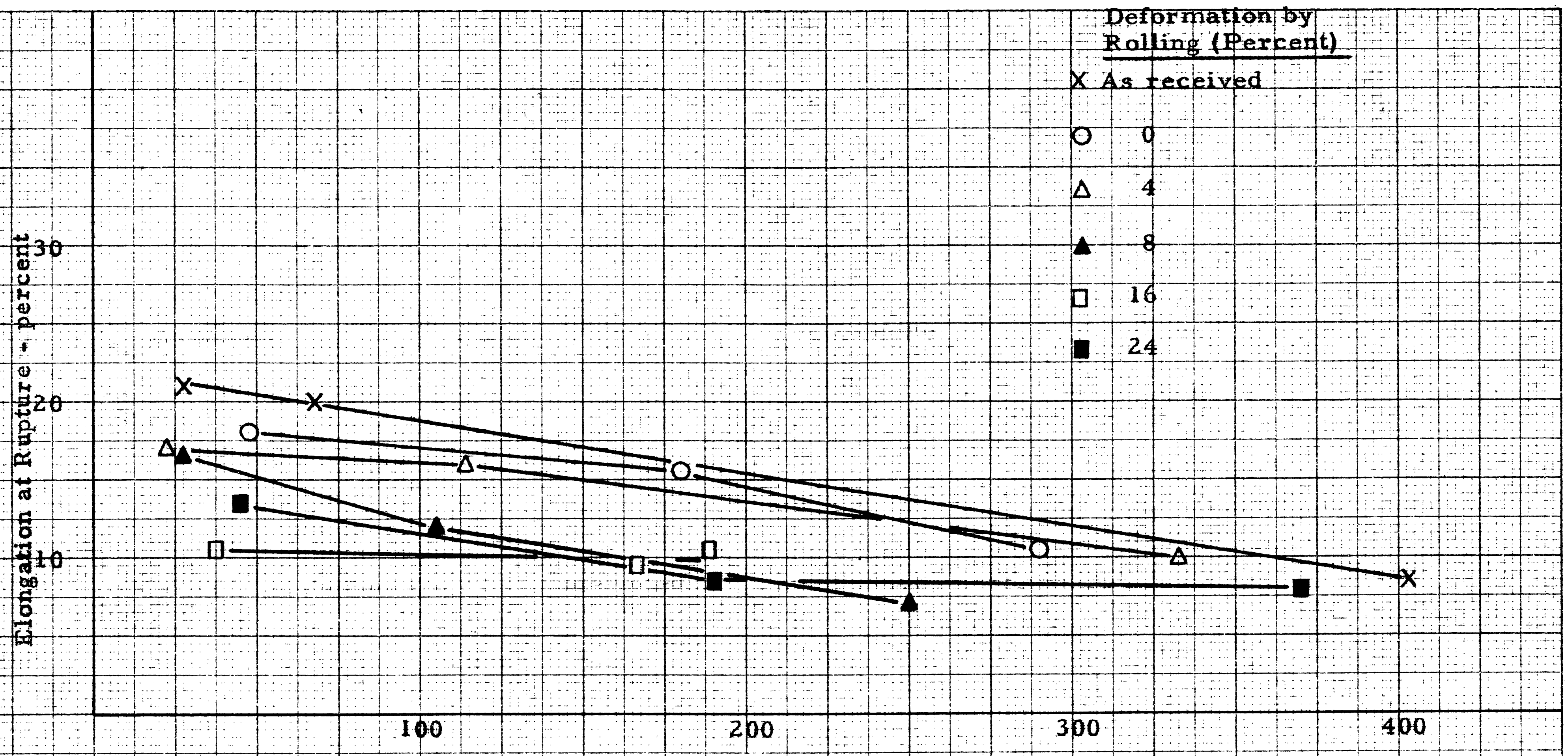

Figure 20. - Effect of various cold reductions on elongation at rupture for various rupture times at 1600°F for N-155 sheet material followed by furnace cooling from 2100°F in hydrogen atmosphere.

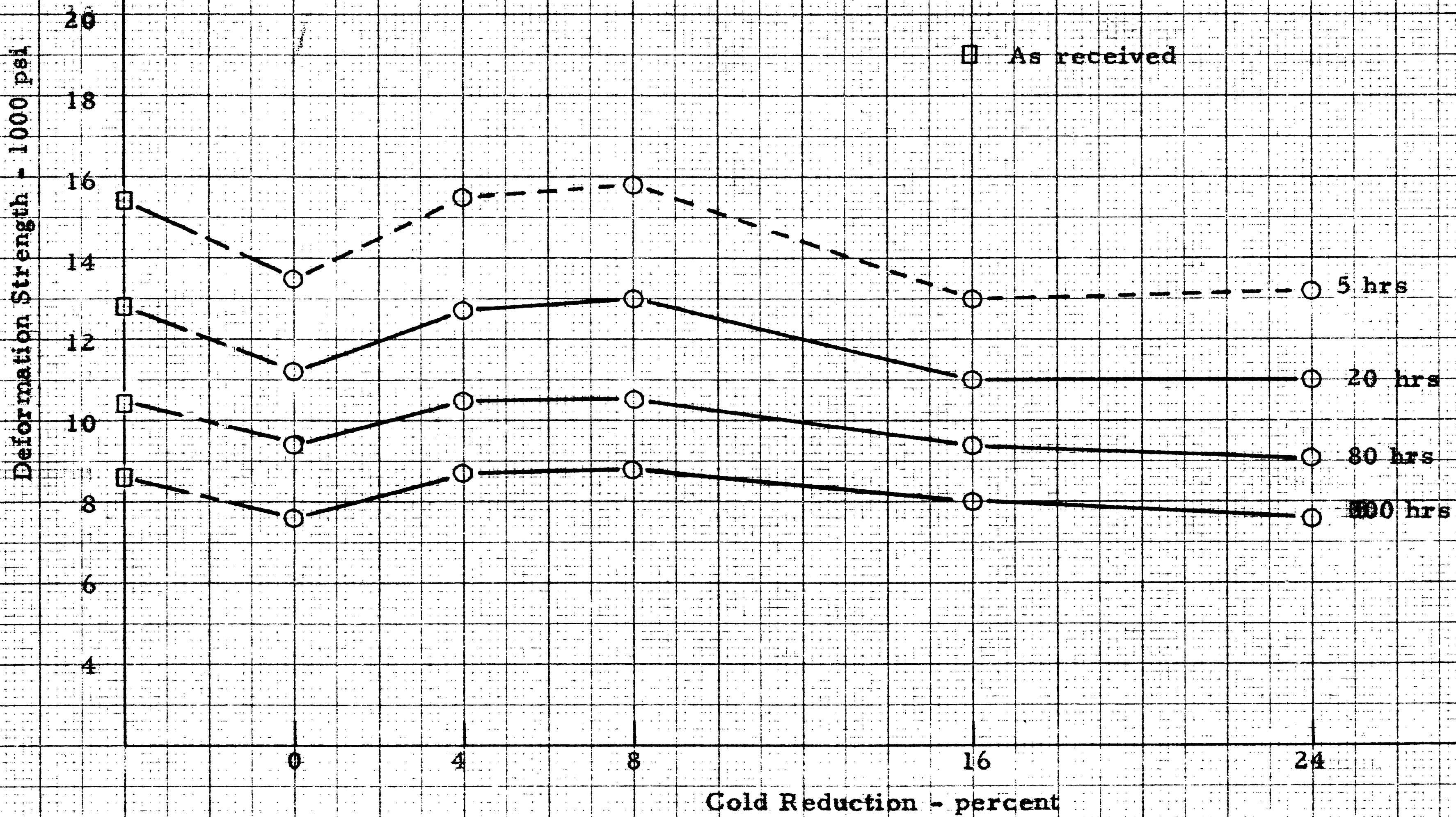

Figure 21. - Summary of the effect on 2% total deformation strengths at 1600°F for N-155 sheet material of various cold reductions followed by furnace cooling from 2100°F in hydrogen atmosphere.

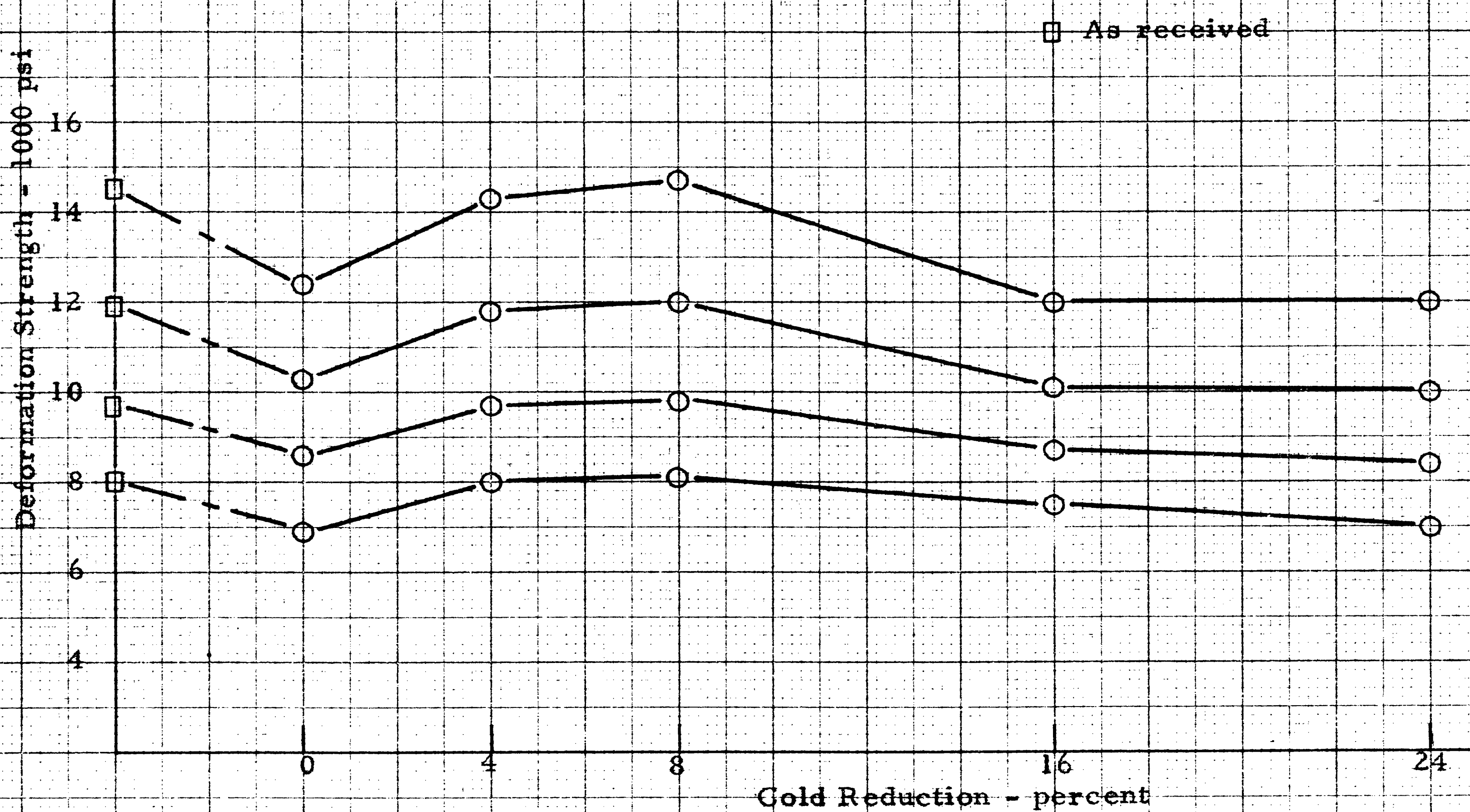

Figure 22. - Summary of the effect on 1 % total deformation strengths at 1600°F for N-155 sheet material of various cold reductions followed by furnace cooling from 2100°F in hydrogen atmosphere.

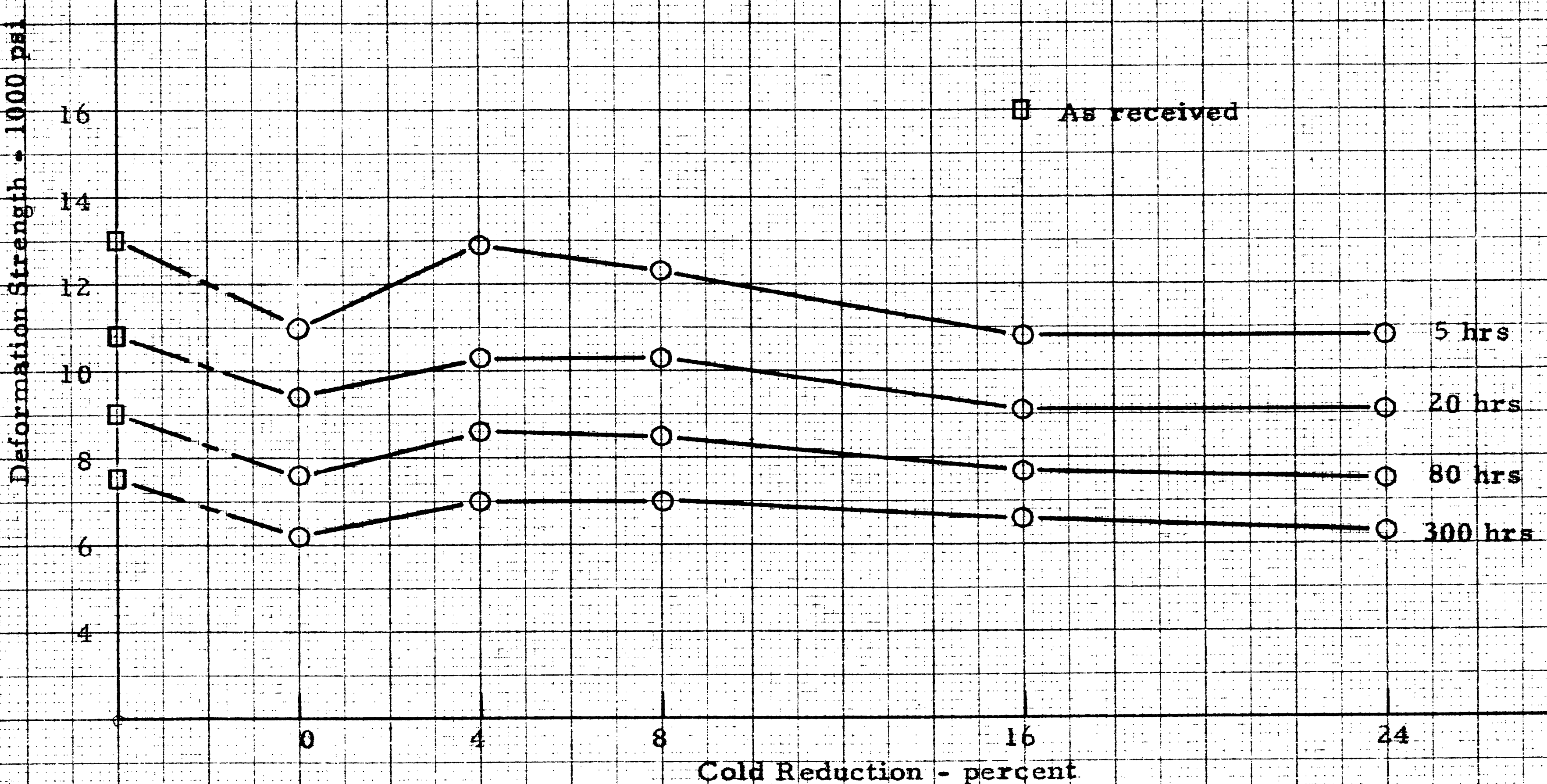

Figure 23. - Summary of the effect on 0.5% total deformation strengths at 1600°F for N-155 sheet material of various cold reductions followed by furnace cooling from 2100°F in hydrogen atmosphere.

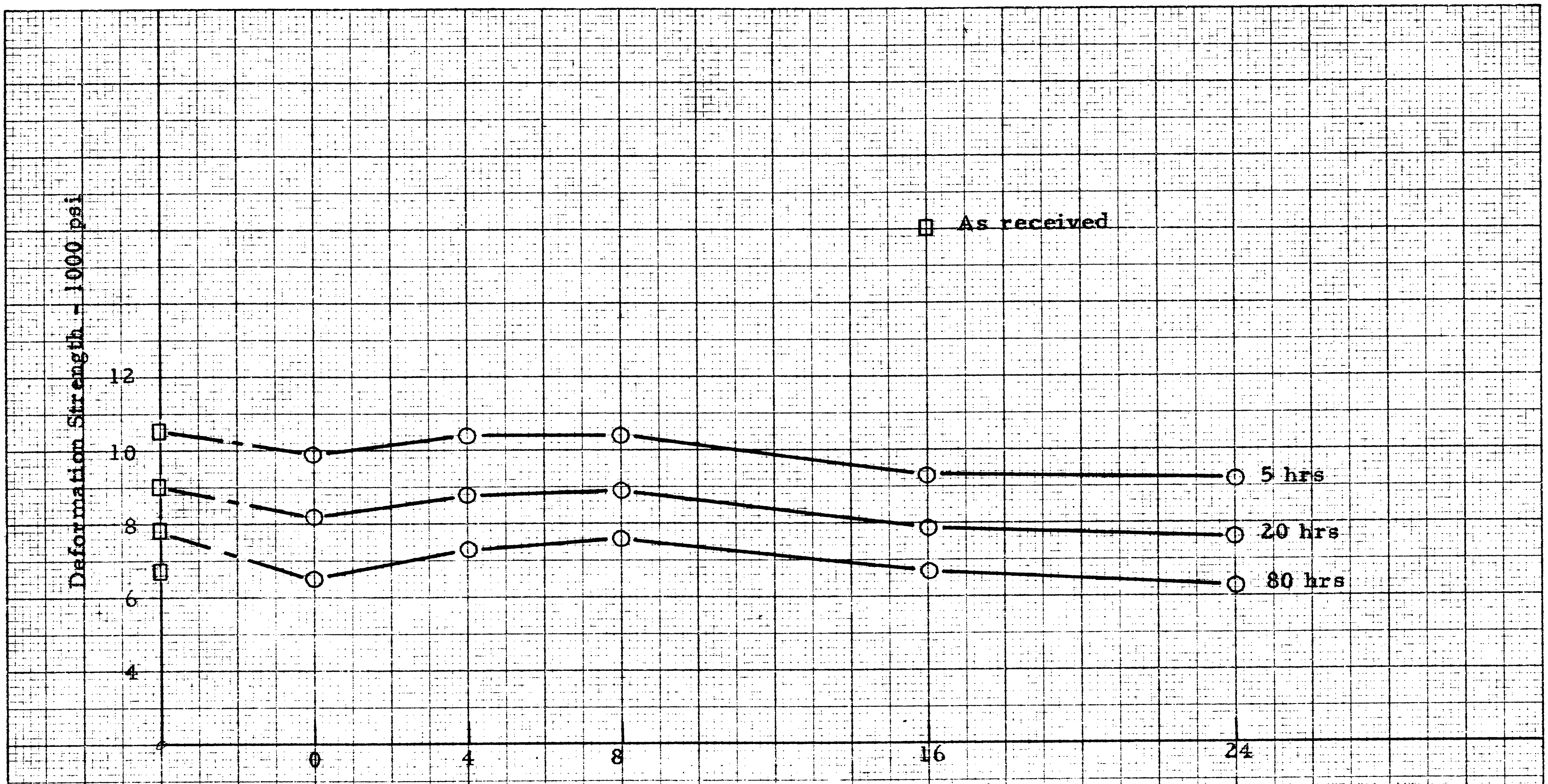

Figure 24. - Summary of the effect on 0.2% total deformation strengths at 1600°F for N-155 sheet material of various cold reductions followed by furnace cooling from 2100°F in hydrogen atmosphere.