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The Effect of Elevated Temperature Exposure on Residual Stresses

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SPALLING OR BRINELLING HAD OCCASIONALLY been noted where a hemispherically shaped part slid on a flat plate. Both parts were of steel, AISI 52100 hardened to 60 R_c. To circumvent what was felt to be a contact fatigue problem, both parts were shot peened since shot peening has been found to be an effective means of increasing fatigue life (1) (2) (3)*.

The problem persisted. One potential reason for this was felt to be an annealing effect upon the residual stress produced by peening. With the parts operating in a lubricant environment at 250-300°F and with the potential of a 50-75°F higher temperature at the contact zone, the annealing posibility seemed quite realistic and worthy of evaluation.

Consequently, an investigation of the residual stress patterns of shot peened AISI 52100 and AISI H-11 (a more temperature resistant steel) after prolonged exposures to moderate temperatures was conducted.

PROCEDURES

Shot peened specimens of 52100 and H-11 materials were placed in atmosphere furnaces for 1, 10, 100, 1000 and 4000 hours. One sample was used for each period of time except 4000 hours where 2 samples were used. For the 52100 parts temperatures of 250° F, 300° F, 400° F and 600° F were employed. For the H-11 specimens, temperatures of 400° F, 600° F and 800° F were used. Residual stress levels in all of the samples were then checked at .004" depth intervals by grinding .002" and then chemically polishing .002". The residual stress was ascertained via X-ray diffraction techniques (4), (5), (6).

RESULTS

The normal stress distribution for shot peened specimens in the as peened condition is shown in Figure 1.

The isothermal residual stress plots of the 52100 are shown for 250, 400, and 600° in Figures 2, 3 and 4, respectively. The data for 300° F essentially duplicates the results at 250° and are not shown.

Figure 5 shows the residual patterns after 4000 hours at temperature and are the averages of 2 specimens each with a maximum spread between readings of 11 ksi. As one would expect, it shows a gradual decrease in the peak residual stress as the temperature is increased.

Although fewer specimens were employed, basically the same results were obtained with the H-11 except that a higher temperature was required for a significant drop in the peak residual stress. The isothermal data for H-11 at 400° F and

*Numbers in parenthesis refer to references at the end of the paper.

ABSTRACT

Shot peening is commonly used to create residual compressive stresses in part surfaces, thereby reducing the effects of tensile service loads and improving fatigue life.

The research reported here was initiated to determine whether or not the residual compressive peening stresses are rapidly annealed out by elevated temperature exposures. AISI H-11 and 52100 steels were selected for the tests, peened, and subjected to temperatures up to 800° F for times to 4000 hours. Residual stress measurements were made by X-ray diffraction methods.

It was shown that residual stresses are not significantly relieved in 52100 within 10 hours at 400° F, or 4000 hours at 300°F. For H-11, no change was produced within 10 hours at 800° F or 4000 hours at 600° F. It was found possible to relate the reduction in initial residual compressive stress level caused by thermal stress-relief by a parameter of the form $P = T(c + \log t)$.

600° F is plotted in Figure 6 while the isothermal data at 800° F is plotted in Figure 7. Figure 8 is the data on H-11 after 4000 hours at temperature.

To check the effect of heat treatment on non-shot peened samples, a number of the H-11 specimens were checked on their non-shot peened surfaces. No effect of temperature was noted as can be seen in Figure 9.

For ease in assimilation of the data in future applications, time - temperature parameter curves were prepared and are shown in Figure 10 and 11. These curves are normally developed for creep or tempering effects, but since this was felt to be a similar phenomenon were compiled also for this stress relieving effect.

DISCUSSION OF RESULTS

A. Isothermal Data for 52100

Figures 2 through 5 present the results of holding shot peened specimens for various lengths of time at moderate temperatures. With the exception of the data for 4000 hours at temperature, where duplicate specimens were employed, only one specimen was used for each period of time. Possibly due to this lack of duplicate sampling, some apparent anomalies exist. For example, there is a higher peak compressive stress after 10 hours at 400° F than there is after only 1 hour at 250° F and there is a higher peak compressive stress after 4000 hours at 250°F than there is after 100 and 1000 hours at 250°F. However, in all of these cases the

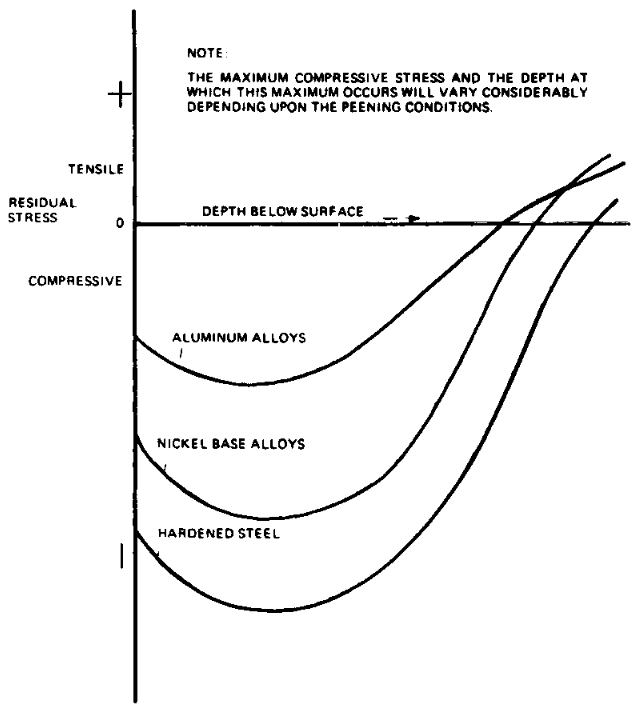

Fig. 1 - Normal high intensity shot peening stress distribution

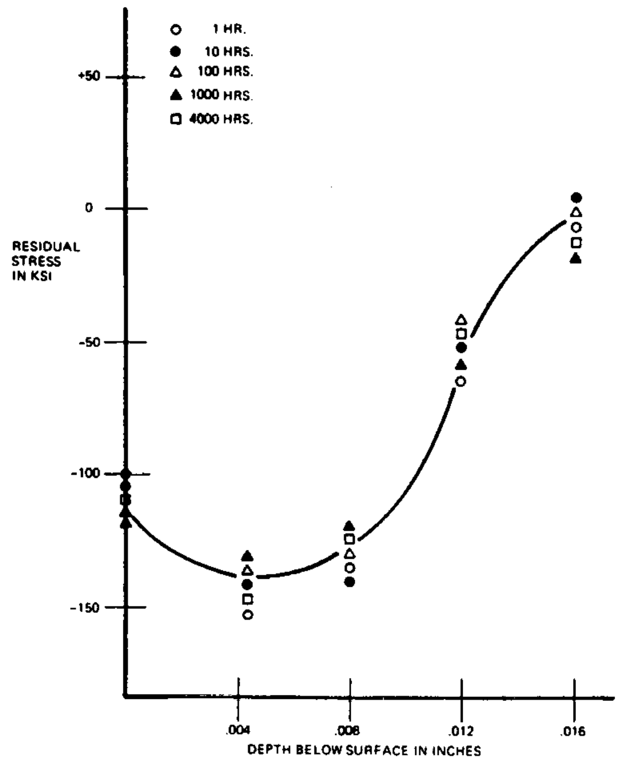

Fig. 2 - Isothermal data on 52100 at 250 F

TABLE I

Nominal Chemical Composition of Alloys Employed

Alloy	Alt. Desig.	C	Si Max	Mn Max	Cr	Fe	Ni	Mo	Cu	V
AISI 52100	AMS 6440	1.05	0.35	0.45	1.5	Bal	0.25 Max	.06 Max	.35 Max	
AISI H-11	AMS 6484	0.4	1.0	0.4	5.0	Bal		1.3		0.5

difference is less than about 20 ksi which appears to be a reasonable number for the spread or scatter between specimens particularly at the high end of the scale.

In spite of this scatter, looking at Figure 5 which is based upon duplicate specimens, one can state that there is a significant drop in the residual stress and hence upon the effectiveness of shot peening after 4000 hours at 600° F. In fact, comparing the curves in Figure 4 with those in Figures 2 and 3, a general overall reduction in the amount of the residual compressive stress can be noted after relatively short times at 600°F.

Referring now to Figure 2 where the isothermal data at 250°F is plotted, there is no discernible effect of the period of time at temperature upon the residual stress pattern either in shape or magnitude. Basically, the same order of magnitude and values were obtained at 300° F as at 250° F so that Figure 2 can be considered the results for both 250 and 300° F.

Based upon this data, one would expect no appreciable reduction in the effectiveness of the shot peening at temperatures up to 300° F with 52100 for long periods of time. One potential discrepancy in this argument is that all of the data for 250° F and 300° F appears to be about 20-30 ksi lower than the data obtained at room temperature or the normal shot peening stress distribution shown in Figure 1 and 5. Two possible causes for this difference are (1) a slight stress relieving effect or (2) the normal scatter in the stress levels obtained by peening. The data in Figure 5 after 4000 hours at temperature lends credance to the stress relieving concept, while the data at 400° F after 1 and 100 hours tends to point to a scatter phenomena.

The data at 400° F shown in Figure 3 shows the expected trend. That is a slight drop in peak compressive stress as the time at temperature increases. If the data in this figure is compared with the data in Figure 5 and 6 only, no difficulties arise. Comparison with Figure 2 leads to some problem, for

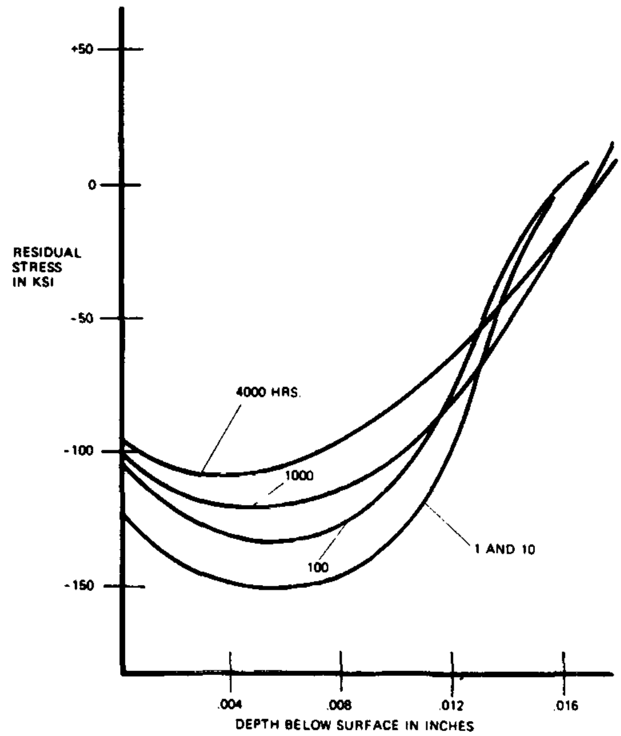

Fig. 3 - Isothermal data on 52100 at 400 F

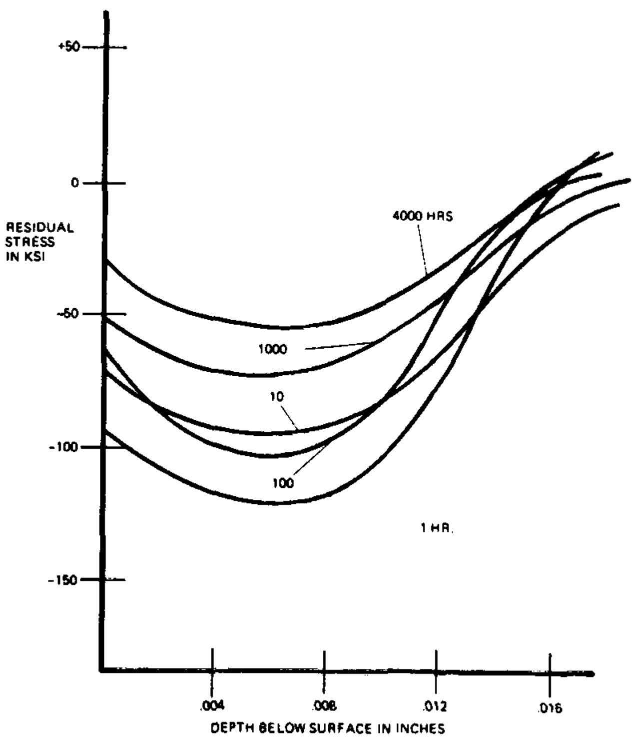

Fig. 4 - Isothermal data on 52100 at 600 F

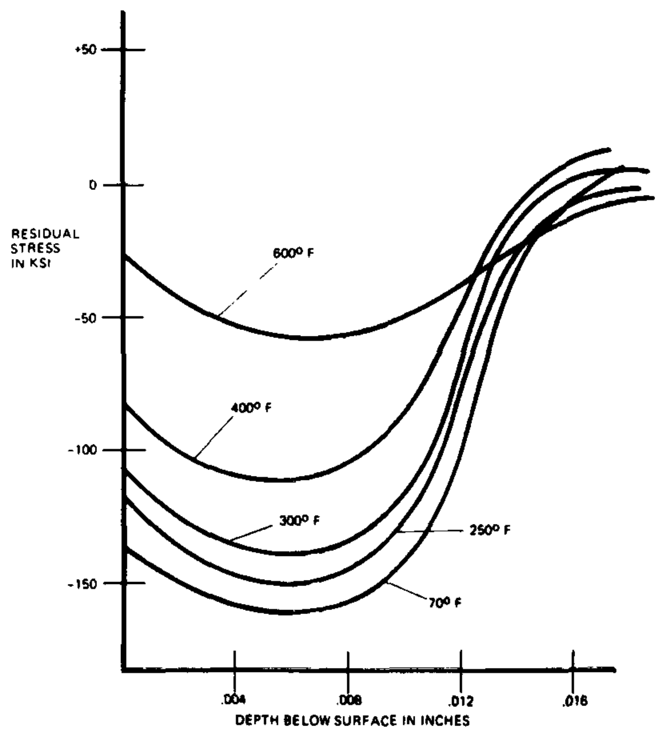

Fig. 5 - Data on 52100 after 4000 hr at temperature

TABLE II

Data on 52100 After 4000 Hours at Temperature

Numbers are compressive residual stress in KSI and the numbers in parenthesis are the averages

Temp.	Surface	–004" Below Surface	–008" Below Surface	Average* Difference
Room Temp.	117	152	108	
	128	154	115	
	154	168	133	0
	(133)	(158)	(119)	
	112	125	93	
250°F	128	131	107	21
	(120)	(128)	(100)	
	105	122	98	
300°F	112	112	88	30
	(109)	(117)	(93)	
	90	105	56	
400°F	99	106	53	52
	(95)	105)	(55)	
	32	56	2	
	27	66	1	106
	(30)	(61)	(2)	

* This number was obtained by taking the differences between averages and then averaging that. Standard deviation between data points for the same depth = 14.5

the peak compressive stress after 1 to 10 hours at 400°F is greater than the peak compressive stress after 1 to 10 hours at 250 and 300° F. As mentioned before this does tend to point to a scatter phenomena. However, in spite of this problem a couple of rational conclusions can be drawn. One is that short term exposures (up to 10 hours at least) to temperatures as high as 400° F have no appreciable effect upon the residual stress pattern in 52100. The other is that after long time exposures to 400° F there is a significant drop off in the residual compressive stress.

A temperature of 600° F even for relatively short times causes an appreciable drop in the residual stress as can be seen in Figure 4. Figure 5, which is based upon duplicate specimens, shows a gradual reduction in the residual stress as the temperature is increased. This concept appears valid in spite of the amount of scatter intimated earlier when one compared all of the data to the room temperature or normal distribution curve. This is done in Table II. Looking at the data for 250° F and 400° F, it is much easier to believe a scatter of 21 ksi, the average difference between room temperature and 250° F, than it is to believe a scatter of 52 ksi, the difference between room temperature and 400° F.

The time - temperature parameter curve for 52100 shown in Figure 10 shows all of the data points on the curve. While

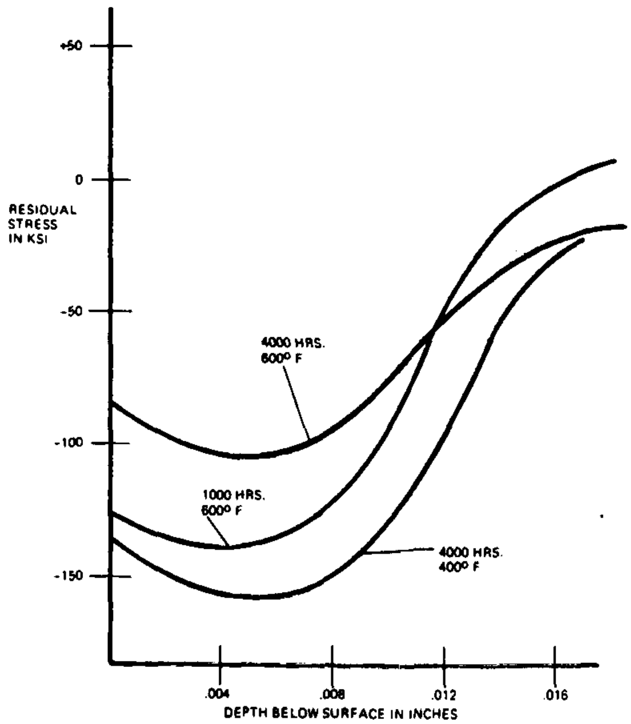

Fig. 6 - Isothermal data on H-11 at 400 F and 600 F

some scatter obviously exists, it seems well within the range of experimental error. Thus the validity of the conclusions above is substantiated. One additional comment is that the curve generated is really valid only when the initial compressive residual stress is 150 ksi.

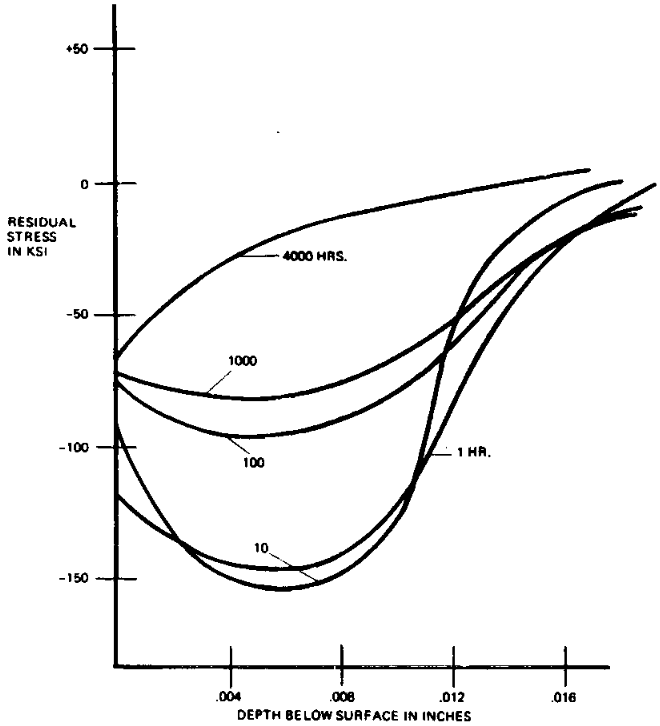

Fig. 7 - Isothermal data on H-11 at 800 F

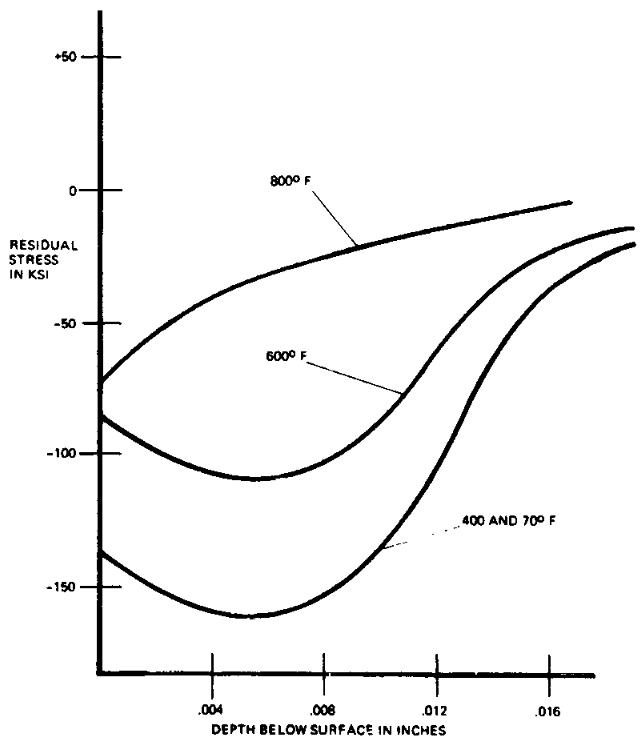

Fig. 8 - Isothermal data on H-11 after 4000 hr at temperature

B. Isothermal Data for H-11

The isothermal data for H-11 is shown in Figures 6 through 9. Figure 9 is data on non-peened specimens. It is interesting to note that time and temperature had no noticeable effect upon the original residual stress pattern which was probably obtained from the grinding operation. All

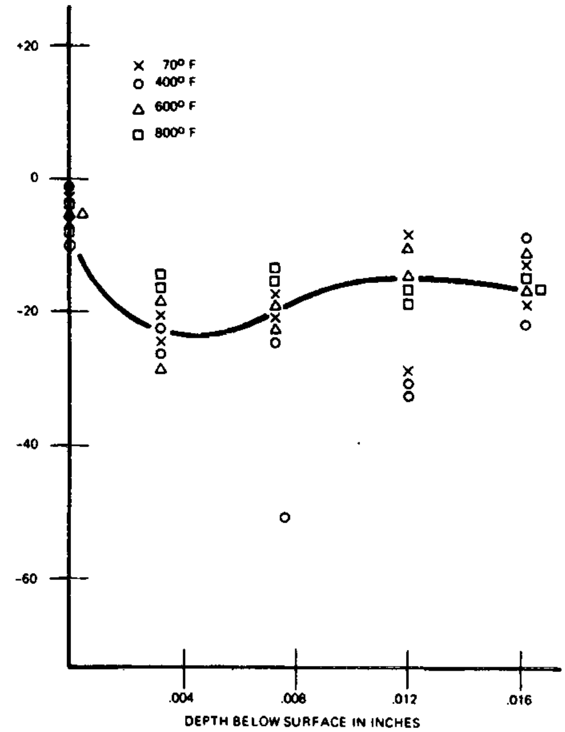

Fig. 9 - Isothermal data on H-11 not shot peened after 1000 and 4000 hr exposure

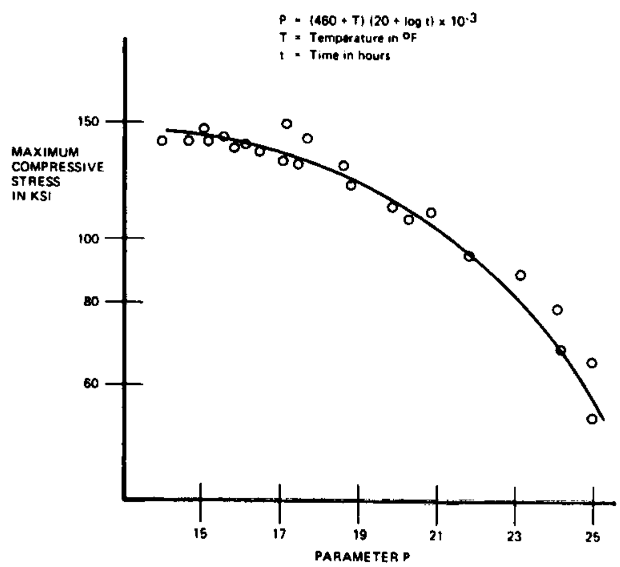

Fig. 10 - Master stress-relief curve for 52100. Time-temperature parameter curve for AISI 52100 at 60 R_c shot peened to an initial maximum compressive stress of 150 KSI. (Almen = 1002 minimum)

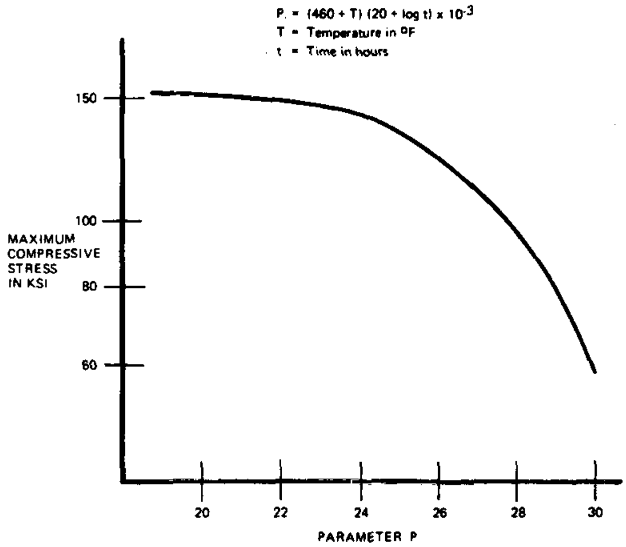

Fig. 11 - Master stress-relief curve for H-11. Time-temperature parameter curve for AISI H-11 at 53 R_c shot peened to an initial maximum compressive stress of 150 KSI. (Almen = 1002 minimum)

of the specimens were processed at the same time and the data was obtained from the bottom or unpeened surfaces of those specimens utilized for the remainder of the testing discussed below.

Returning to the isothermal data, Figure 6 shows that the H-11 is unaffected by long times at temperatures of 400° F and only slightly reduced by as long as 1000 hours at 600° F. Shorter times at higher temperatures (for example 10 hours at 800° F) also indicate no appreciable reduction in residual stress level. This corresponds well with the results published in ref. (7) which showed no reduction in shot peened fatigue life after 4 hours of exposure at 1000° F. Unfortunately longer times at temperature were not checked in ref. (7).

Basically the same types of data were noted for the H-11 as for the 52100 only the stress relieving effects occured at a 200 - 400° F higher temperature. The long term data (4000 hours) is shown in Figure 8 and there appear to be no problems associated with long term exposures up to 400° F.

The H-11 time - temperature parameter curve is shown in Figure 11, and basically the same comments made for the 52100 apply here. The basic difference is that higher temperatures are of interest with the H-11 so that larger parameter values are utilized.

CONCLUSIONS

1. With AISI 52100 bearing steel no appreciable change in the magnitude or shape of the residual stress curve due to shot peening, which is indicative of the retention of increased fatigue life, occurs under the following conditions:
   a) Long term (up to 4000 hours) exposure up to 300° F.
   b) Short term (up to 10 hours) exposure up to 400° F.
2. AISI 52100 did show significant residual stress reduction after long term exposure at 400° F and short term exposure at 600° F.
3. AISI H-11 showed no significant change after long term exposure (4000 hours) at 400° F or short term (10 hours or less) exposure at 800° F.
4. AISI H-11 did show significant reduction after long term exposure at 600° F and above.
5. It was found possible to relate the reduction in initial residual compressive stress level caused by thermal stress-relief by a parameter of the form $P = T (C + \log t)$.

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