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... in the inner part offer little effect on fatigue strength. On the contrary, it would be detrimental to surface topography and decreasing the fatigue limit. If the contributions of surface topograhy and micro-stress relief to the fatigue limit are not properly evaluated, the effect of residual stress would be greatly exaggerated. Assuming a line is drawn in fig.3 connecting the data of ground and peened specimens, one would find that its slope should be 0.34. The slope could be larger if the surface residual stress value is used. However, it is an approach of phenomenological view instead of intrinsic correlation.

CONCLUSIONS

1. In high carbon hardened steel, compressive residual stress in the surface layer of a smooth specimen prolongs transgranular crack depth and reduces the portion of intergranular fracture. It occurs within the range of 0.1mm. Thus, in an engineering sense residual stress can affect on fatigue crack initiation.

2. Average residual stress in low crack growth rate region bears an aspect as mean stress, the slope is about 0.10 in Goodman relationship.

3. Fatigue crack initiates at the bottom of grinding scratch or peening dent and then grows inwards. Shot peening lessens the surface detriment due to grinding and reduces microstress as well. Normally, these two factors are more significant than residual stress in high carbon steel.

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Behavior of Peen-Formed Steel Strip on Isochronal Annealing

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ABSTRACT

X-ray residual stress measurements and precision curvature measurements were made on rectangular steel strips that had been peen-formed and then subjected to different isochronal annealing treatments. The initial surface residual stress and curvature levels were substantially greater for the transverse than for the longitudinal direction. Relief of both curvature and residual stress occurred that increased with temperature up to 400°C. No further relief was observed above this temperature. The relief of curvature reached 52% for the transverse direction and 40% for the longitudinal direction as compared to more than 95% of the residual stress. An anomalous effect was found for annealing at 425°C.

Key words : Peen-forming, Residual Stress, Isochronal Annealing, Stress Relief.

INTRODUCTION

Peen-forming is well-established (Johnson, 1968) as a commercial process for manufacturing curved components in sheet materials. The shape changes associated with peen-forming are due to two factors (i) inhomogeneous plastic deformation and (ii) a bending moment caused by the induced residual stress pattern. Inhomogeneous plastic deformation would be expected to introduce a permanent shape change whereas the contribution due to residual stress should be affected by any subsequent stress-relieving treatments. The object of this research was to determine the effect of isochronal annealing on the surface residual stress and the curvature of peen-formed steel strips.

EXPERIMENTAL METHODS

The material selected for this investigation was a set of 12 standard Almen "A" test strips that had been shot-peened using identical conditions. The resulting curvature was measured using a precision micrometer mounted on an "Engineers Stand". Each strip was moved under the micrometer between stops set to give traverses of 70.00 and 15.50mm for longitudinal and transverse radius calculations respectively. The corresponding radii

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[illegible] computer-assisted 'Talysurf' equipment was used to confirm that the radii were reasonably uniform for both traverses.

Residual micro-stresses were measured for each strip in terms of the 'half-peak breadth' of the 211 X-ray diffraction line appearing at about 156° 2θ using Cr radiation. Residual macro-stresses were measured using a standard two-exposure X-ray diffractometer technique again involving the 211 profile and Cr radiation. The precision of each stress measurement was established (Kirk and Caulfield, 1977). Sub-surface stress measurement required uniform layer removal from one side only. This was accomplished with a chemical polishing technique with each layer removal being obtained from the corresponding weight loss. Measured residual stresses were corrected for the stress in the removed layers (Moore and Evans, 1958).

Isochronal annealing was carried out in an air-circulatory furnace with specimen temperatures being held to ±0.5°C.

RESULTS AND DISCUSSION

The results of the radius measurements on both as-peened and annealed strips are given in Table I and the changes are presented as Fig.1. The as-peened strips had a much greater curvature in the transverse direction (mean radius 446 mm) than in the longitudinal direction (mean radius 678 mm). This is a general characteristic of peen-forming with the type of restraint imposed by the Almen Gauge. Annealing has given a generally progressive reduction in curvature with increase in annealing temperature (see Fig.1). Curvature relief reaches about 52% for the transverse direction as compared to about 40% for the longitudinal direction. The residual curvature is still, however, much greater for the transverse direction. A second feature is the anomalous effect at 425°C which gives less curvature relief but was found to be reproducible. It is believed that this phenomenon is associated with precipitation. Further study will be needed in order to elucidate the situation.

Fig.2 shows the results of X-ray residual macro-stress measurements on an as-peened-formed specimen. The stress profile has the characteristic features generally associated with peen-forming. The peened surface has a high level of compressive stress, about -450 MPa, which extends to a depth of 0.10 mm and then gives way to balancing sub-surface tensile stresses. Concave bending of the surface opposite to the peened surface has induced a surface stress of -170 MPa. This bending is also the source of the linear region of stress variation that extends from the unpeened surface to about 0.20 mm below the peened surface. The presence of residual compressive stresses on both major surfaces is the advantageous situation that normally exists in as-peened-formed components.

Table II gives the results of X-ray residual macro-stress measurements made on the specimens whose curvature relief was measured (see Fig.1.). These results show several interesting features. For the as-peen-formed condition there is a substantial range of stress levels for nominally identical specimens. In the longitudinal direction the range for the peened surface is from -230 to -532 MPa and from -553 to -748 MPa in the transverse direction. The mean value in the longitudinal direction is much lower, at -436 MPa, than the -651 MPa for the transverse direction. In the case of the unpeened surface the mean values are much closer at -180 and -221 MPa respectively for longitudinal and transverse directions.

These latter values, since they represent stresses [illegible] indicate that the corresponding curvature should be greater in the transverse direction. This agrees with the finding of a 446 mm mean radius for the transverse direction and only 678 mm for the longitudinal direction. Since, however, this bending also induces stress relief of the peened surface it means that the as-clamped values of residual surface macro-stress would have shown an even greater disparity between longitudinal and transverse directions. Isochronal annealing of the peen-formed strips has lead to a progressive fall in surface stress up to about 400°C where the maximum stress relief is about 95%. It should be noted that complete stress relief can only be achieved by using very high temperatures inducing either a phase transformation or recrystallisation. The observed stress relief follows a very similar trend to the curvature relief with stabilisation at about 400°C.

Table III gives the results of line breadth as affected by isochronal annealing. The observed sharpening of the diffraction line with increase in annealing temperature is consistent with both the relief of curvature and of macro-stress. This is to be expected as annealing induces migration and annihilation of dislocations which are the major source of line broadening in peened material.

In practical situations peen-formed sheets are normally held in position as integral parts of larger components. If such components were to become heated then curvature relief would be restrained. This restraint would, however, involve tensile stresses being set up at the retaining points which would become potential sources of stress corrosion. A loss of protective compressive surface residual macro-stress in the sheet surfaces could not be avoided.

CONCLUSIONS

It may be concluded from this work that:

(i) Isochronal annealing of peen-formed steel strip gives a partial relief of curvature reaching maxima of about 52% for the transverse direction and 40% for the longitudinal direction.

(ii) The partial relief of curvature on isochronal annealing is due to the removal of residual stresses. The curvature that remains is the stable component of bending induced by inhomogeneous plastic deformation.

(iii) Residual surface macro-stresses are much higher in the transverse direction of the rectangular strips being an average of -651 MPa as compared with -436 MPa for the longitudinal direction. This is in spite of the greater curvature in the transverse direction (446 mm cf 678 mm).

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Table I Influence of Isochronal Annealing on Radii of Peen-formed Steel Strips

Condition	Longitudinal radius - mm	% Change	Transverse radius - mm	% Change
As-peened	754	-	444	-
As-peened	653	-	395	-
200°C/1h	682	4.4	397	0.5
As-peened	618	-	396	-
300°C/1h	716	15.9	448	13.1
As-peened	700	-	532	-
325°C/1h	857	22.4	683	28.4
As-peened	705	-	581	-
350°C/1h	901	27.8	820	41.1
As-peened	619	-	381	-
375°C/1h	803	29.7	581	52.5
As-peened	736	-	461	-
400°C/1h	1023	39.0	703	52.5
As-peened	644(690)*	-	413(402)*	-
425°C/1h	809(876)*	25.6(27.0)*	561(553)*	35.8(37.6)*
As-peened	670	-	448	-
450°C/1h	935	39.6	684	52.7
As-peened	701	-	461	-
475°C/1h	978	39.5	701	52.1
As-peened	642	-	437	-
500°C/1h	892	38.9	666	52.4

* - Duplicate specimen measurements.

Table II Influence of Isochronal Annealing on Surface Residual Macro-stresses in Peen-formed Steel Strips

Condition	Residual Macro-stress - MPa: Peened Longit.	Peened Transv.	Unpeened Longit.	Unpeened Transv.	% Change
As-peened	-230	-554	-174	-236	0
As-peened	-416	-742	-176	-257	-
200°C/1h	-434	-480	-196	-192	18.2
As-peened	-401	-678	-181	-216	-
300°C/1h	-294	-403	-144	-148	33.0
As-peened	-427	-553	-192	-197	-
325°C/1h	-244	-348	-133	-158	36.1
As-peened	-462	-670	-164	-210	-
350°C/1h	-164	-261	- 84	- 84	60.6
As-peened	-532	-701	-205	-222	-
375°C/1h	-121	-146	- 71	- 63	75.8
As-peened	-557	-625	-167	-203	-
400°C/1h	+ 35	- 33	- 46	- 36	94.8
As-peened	-382	-748	-192	-241	-
425°C/1h	- 30	- 25	- 8	- 7	95.5
As-peened	-427	-641	-174	-204	-
450°C/1h	- 25	- 25	- 6	- 8	95.6
As-peened	-482	-666	-181	-234	-
475°C/1h	- 22	- 20	- 9	- 10	96.1
As-peened	-454	-658	-190	-211	-
500°C/1h	- 23	- 20	- 12	- 8	95.8

Table III Changes in Surface Residual Micro-stress Induced by Isochronal Annealing of Peen-formed Steel Strips.

Annealing Temperature -°C	211 Line Breadth - °2θ: As-peened	As-annealed	% Change
200	3.30	3.10	6.5
300	3.10	2.64	14.8
325	3.36	2.48	26.2
350	3.18	2.38	25.2
375	3.28	2.14	34.8
400	3.32	2.14	35.5
425	3.24	2.04	37.0
450	3.29	2.07	37.1
475	3.40	2.08	38.8
500	3.18	1.90	40.2

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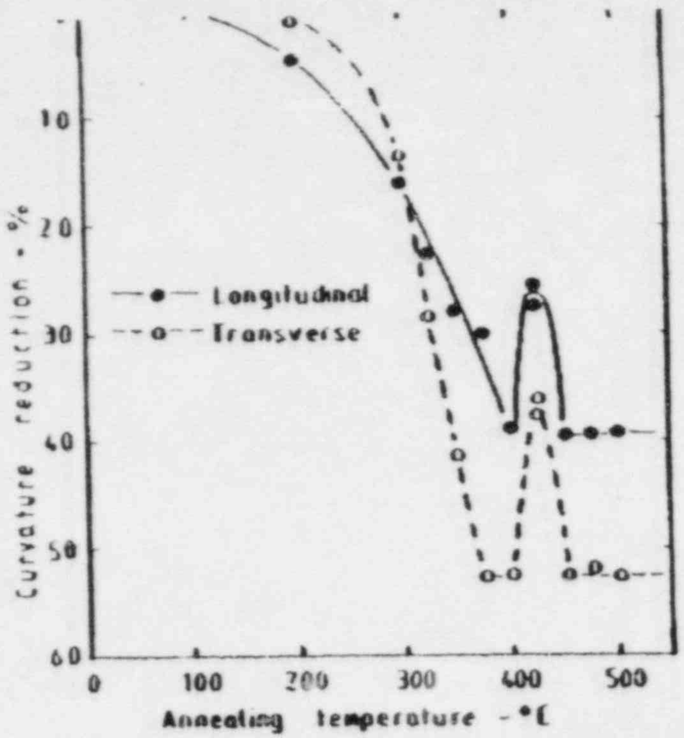

Fig. 1 Curvature relief on Isochronal Annealing

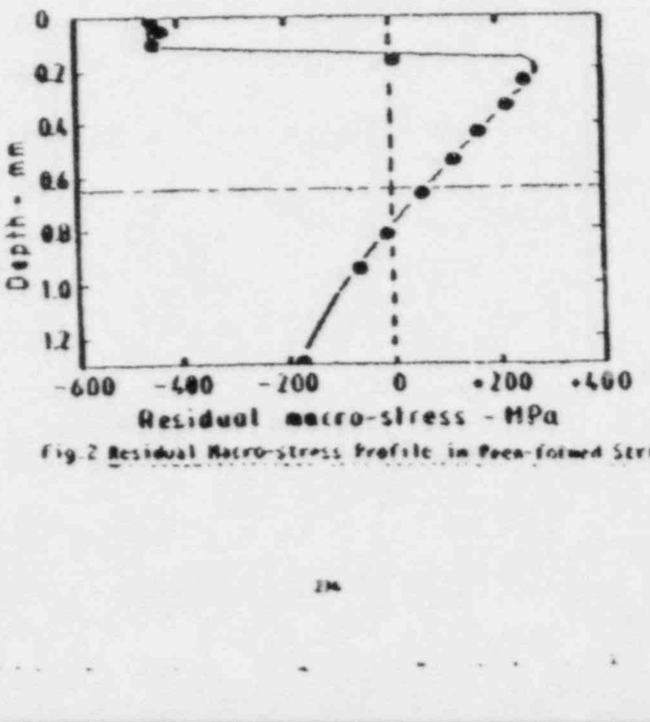

Fig. 2 Residual Macro-stress Profile in Peen-formed Strip

Influence of Shot Peening on the Residual Stresses in Spring Steel Plate

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ABSTRACT

The influence of six different SAE cast steel shot sizes (S-280, S-330, S-390, S-460, S-550, and S-660), measured under constant flow rate of 454 kilograms per minute and the travel speed of the work piece through the blast adjusted to obtain 98 percent coverage in one pass are reviewed as to their induced residual stresses on SAE 5160 leaf spring coupons.

Ten coupons were shot peened with each shot size in the intensity range of 5C to 14C. Random coupons were then checked for residual stress by x-ray diffraction analysis to a depth of .350 mm. Curves were then plotted showing residual stress versus depth below the surface for each coupon. A comparison can then be made of coupons for each shot size and shot intensity as to the residual stresses.

The data was then analyzed mathematically to confirm the conclusions inferred by the composite curves. Cubic parabola regression equations are used to closely predict the measured stress value. The regression curves, plotted from the calculated stress values are compared to the measured stress for each coupon.

KEYWORDS

Shot peening; steel; residual stress; x-ray diffraction; regression equations; fatigue.

INTRODUCTION

In the manufacture of suspension leaf springs shot peening is vital for improving their fatigue life. The benefits of shot peening both in free state and pre-stressed conditions are well documented and have been substantially developed. Specifications on leaf spring manufacture now require a compressive residual stress at a specific depth below the surface.

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