Improvement of Ni 18 (250) Maraging Steel Weldment Fatigue Strength Through Shot Peening

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Introduction

The low fatigue strength of weldments limits the design stresses of welded components. Fortunately, the fatigue strength of weldments can be substantially increased by shot peening and by other post-weld treatments which alter the severity of the critical notch, increase the notch root material's fatigue resistance (strength), or induce favorable residual stresses at the notch root.

This study investigated the effects of various shot peening treatments on the fatigue resistance of groove weldments in thin gauge (3 mm) sheets of a maraging steel fatigued under reversed bending. The results of the experiments were compared with two analytical models for the fatigue strength of weldments. Comparison of theory with experiment lead to the conclusion that not all shot peening treatments cause substantial improvements in the fatigue resistance of weldments.

Materials, Experimental Procedures, and Results

A maraging steel Ni 18 (250) was used in this study which had the composition and mechanical properties after aging given in Tables 1 and 2.

C%	Mn%	P%	S%	Si%	Ni%	Mo%	Ti%	Co%	Al%
0.02	0.01	0.008	0.007	0.08	18.29	5.40	0.34	7.31	0.01

Table 1: Chemical Composition of Ni 18 (250) Maraging Steel.

Panels of 3 mm thickness maraging steel Ni 18 (250) were joined using GTA welding and filler metal of similar composition. Test pieces shown in Fig. 1 were cut from the fabricated panels and machined to the dimensions shown. Following specimen preparation, all specimens were given an aging heat treatment of 5 hours at 480°C in air. The hardness of all regions of the weldment were quite similar after this aging treatment suggesting rather uniform material properties throughout the weldment.

Four different-shot peening treatments were given to the testpieces after aging:

a) 0.1 mm dia. glass beads delivered in a compressed-air stream
b) 1 mm dia. steel shot delivered in a compressed-air stream
c) 1 mm dia. steel shot delivered in a compressed-oil stream
d) 0.5 mm dia., 1.5 mm length chopped-steel fibers delivered in a compressed air stream.

Hardness, RHC	50 - 52
Modulus of Elasticity, E (MPa)	186,000
0.2% Offset Yield Strength, S_y (MPa)	1,700
Ultimate Tensile Strength, S_u (MPa)	1,800
Percent Reduction in Area, %RA	55
Fracture Toughness, (MPa $\sqrt{m}$)	120
Elongation in 50 mm, (%)	8
Impact Resistance, (J/cm^2)	20
Critical Stress Intensity Factor, K_c (MPa $\sqrt{m}$)	93
True Fracture Strength, σ_f (MPa)	2,145
True Fracture Ductility, ε_f	0.80
Strain Hardening Exponent, n	0.030
Strength Coefficient, K (MPa)	2,160

Table 2: Mechanical Properties of Ni 18 (250) Maraging Steel after aging 5 hrs at 480°C.

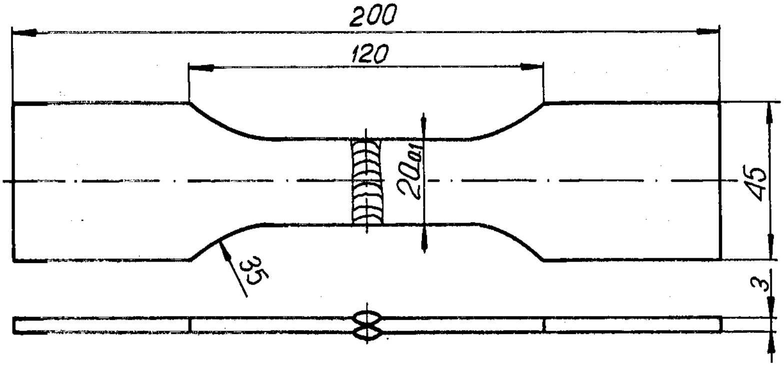

Fig. 1: Fatigue testpiece dimensions in mm.

All specimens were peened for 20 minutes (approximately 100% coverage), that is, until maximum Almen intensity was achieved. The surface residual stresses were measured for the both the aged and aged and peened testpieces using the Weismann-Philips method (3): see Table 3. The post-aging surface residual stress was slightly compressive presumably because of transformation stresses induced by the formation of precipitates. Shot peening in air with steel shot and steel wire induced large compressive residual stress, but only modest residual stresses were induced by the glass beads in air. The steel shot in oil gave intermediate results.

Treatment	Residual Stresses (MPa)	Experimental Fatigue Strength (MPa)	Predicted Fatigue Strength (MPa)		
			Eq. 3 $K_f = 2.6$	Eq. 7 $K_{fmax} = 2.0$	Eq.6
Unpeened (welded/aged)	-67	337	333	427	333
Peened (a) glass/air	-89	344	336	431	336
Peened (b) steel/air	-776	356	439	564	440
Peened (c) steel/oil	-332	341	373	478	373
Peened (d) wire/air	-893	478	456	587	457

Table 3: Experimental results and predicted fatigue strengths.

The testpieces were fatigue cycled in reversed bending (R = -1) under ambient laboratory conditions at a test frequency of 25 Hz. S-N diagrams were determined by testing approximately 20 testpieces per conditions, and the average fatigue strength at $2x10^6$ cycles is listed in Table 3. Surprisingly, all but testpieces peened with cut-steel-wire shot gave essentially the same fatigue strength, but a substantial improvement in fatigue strength was noted for the testpieces treated with the cut-steel-wire shot (see Table 3).

Discussion

Estimates of long-life fatigue strength can be obtained using the Basquin equation as modified for mean stresses by Morrow (6):

$$\sigma_a = (\sigma_f' - \sigma_m) (2N_I)^b \qquad (1)$$

where σ_a is the local (notch root) stress amplitude, σ_f' is the fatigue strength coefficient, σ_m is the local mean stress (the notch-root mean stress plus the local residual stresses after the set-up cycle), $2N_I$ is the reversals devoted to crack initiation and early growth (one cycle equals two reversals) and b is the fatigue strength exponent. The remote stresses can be related to the notch root stresses through the concept of the fatigue notch factor, K_f and Eq. 1 becomes:

$$S_a K_f = (\sigma_f' - \sigma_m) (2N_I)^b \qquad (2)$$

where S_a is the remote stress amplitude and K_f is the fatigue notch factor. When the applied mean stress is zero, σ_m becomes equal to the notch root residual stress σ_r and Eq. 2 may be written:

$$S_a = \frac{\sigma_f'(2N_I)^b}{K_f} \left(1 - \frac{\sigma_r}{\sigma_f'}\right) \qquad (3)$$

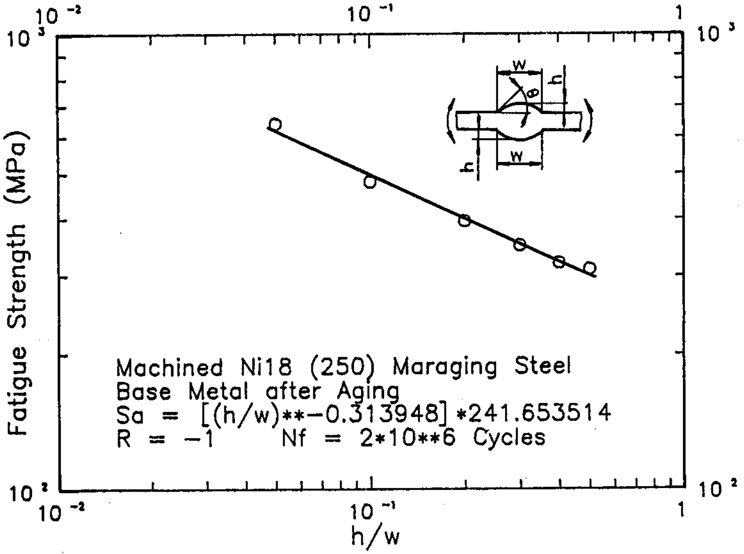

Fig. 2. The effect of reinforcement shape determined by fatigue tests on base metal with simulate welds.

From experiments on machined weld shapes on the same material and plate thickness (Fig. 2), it was found that the effects of weld shape (the ratio of weld height (h) to weld width (w) i.e. (h/w)) upon fatigue strength at 2×10^6 cycles could be expressed by the relationship:

$$S_a = \delta(h/w)^{\beta}$$

From Equations 3 and 4, it follows that:

$$\delta(h/w)^{\beta} = \frac{\sigma_f' (2N_I)^b}{K_f} \qquad (4)$$

Thus the fatigue strength can be estimated as:

$$S_a = \delta(h/w)^{\beta}\left(1 - \frac{\sigma_r}{\sigma_f'}\right) \qquad (5)$$

Yung and Lawrence (6) have developed a similar expression for the fatigue strength of weldments by considering only crack initiation and early growth:

$$S_a = \frac{(\sigma_f' - \sigma_r)\ (2N_I)^b}{K_{fmax}^{eff}\ [1 + \frac{1 + R}{1 - R}\ (2N_I)^b]} \qquad (7)$$

where K^{eff}_{fmax} is the effective fatigue notch factor for the worst-case notch value, and R is the stress ratio, and the other symbols are as previously defined. Values for K^{eff}_{fmax} were estimated from the expression (2,4):

$$K^{eff}_{fmax} = 1 + 0.0015 \alpha S_u t^{0.5} \tag{8}$$

where $\alpha = 0.165\ (\tan\theta)^{0.167}$, S_u is the ultimate tensile strength, t is the thickness of welded plates, and θ is the flank angle.

Values of fatigue strength were calculated using three sources of information regarding the fatigue notch factor: (1) direct experimental results (1,3) i.e. the ratio of smooth specimen to notched specimen fatigue strength at 2×10^6 cycles, (2) estimates using the K^{eff}_{fmax} concept (Eq. 8) and Eq. 7 $K^{eff}_{fmax} = 2.0$, $K_f = 2.6$, (3) the observed dependence of fatigue strength on the ratio h/w (Eq. 6). Predictions made using the measured residual stresses, and these three methods are compared in Table 3 and Fig. 3.

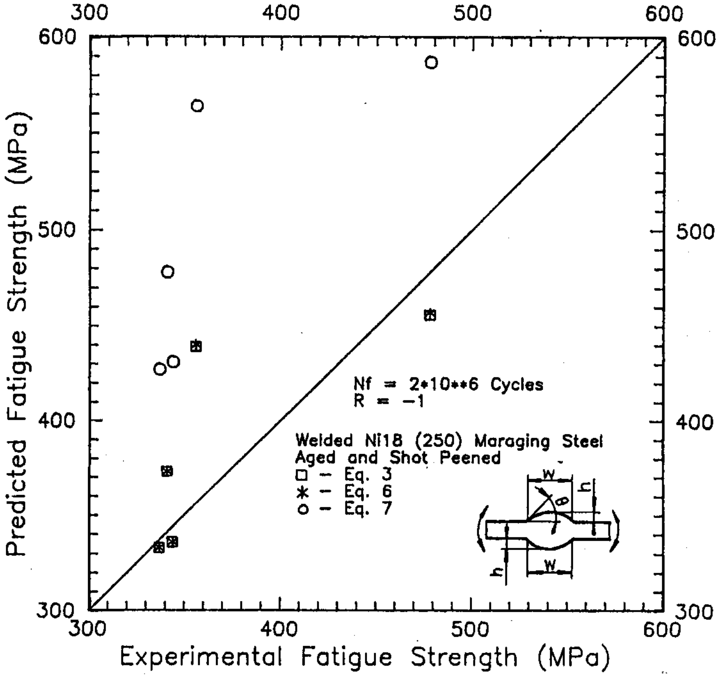

Fig. 3: Comparison of predicted fatigue strength (Equations 3, 6, and 7) with experimental data.

Essentially the estimation of the fatigue notch effect from the two experimental methods (equations 6 and 3) yielded similar results and agreed reasonably well with the experimental data; whereas, the estimates made using K_{fmax}^{eff} and Eq. 7 yielded systematically higher results suggesting that the analytical estimate of K_f from K_{fmax}^{eff} was too small.

None of the three prediction methods predicted the observed fatigue strength for the glass and steel ball peening treatments presumably because these treatments failed to produce the anticipated fatigue strength improvements for reasons which remain unclear.

Conclusions

1. Of the shot-peening methods investigated, only shot-peening with cut-steel-wire significantly increased the fatigue strength of weldments.
2. The fatigue strength predicted using the K_{fmax}^{eff} concept were systematically higher than predictions made using experimental estimates of K_f, suggesting an under estimation of the fatigue notch factor by the K_{fmax}^{eff} concept for very small weldments.

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