THE DEVELOPMENT OF RESIDUAL STRESSES AND CURVATURE IN MILD STEEL BY NEEDLE PEENING

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ABSTRACT

This study has involved a bench-mounted, air-driven, needle gun, with 2 mm diameter flat-ended needles, to apply controlled peening to 3 mm and 6 mm thick mild steel specimens. The induced curvature increased with both air pressure and peening time. Radii of curvature approaching 400 mm and 1600 mm were obtained for the 3 mm and 6 mm thicknesses respectively. Needle peening also induced substantial levels of compressive surface residual stress (-200 MPa) but not as high as those induced by shot peening of the same material (-251 MPa). It has been concluded that needle peening could have useful commercial applications for both residual stress development and peen forming.

KEYWORDS

Needle peening, shot peening, peen forming, steels, residual stress.

INTRODUCTION

The vast majority of commercial peening is carried out using large, closed, shot peening cabinets with associated shot supply and treatment facilities. Exceptions are generally based on captive balls - ranging from simple rotary flaps to the computer-controlled, hydraulically-loaded equipment described by Reccius *et al* (1). Components are, however, normally brought to the facility rather than being peened on-site.

Optimisation of the benefits obtained by peening requires the application of sophisticated control procedures. Controlled shot peening and peen forming are highly-desirable for critical components. It should be remembered, however, that peening is a very 'forgiving' process and a large part of the benefits can be induced by relatively crude peening procedures. With that in mind this research stand. The trigger on the gun was fixed into an 'on' position so that the gun could be activated remotely. The gun used was equipped with sixty-five 2.0 mm diameter flat-ended needles arranged to present a rectangular working area of approximately 35 mm by 10 mm. A schematic representation of the facility is shown as Fig.2. High pressure air was supplied from the same compressor as was used for shot peening. Peening was carried out by feeding 40 mm wide steel strip between guides under the gun. The gun was lowered to the stop giving touching contact of the needles with the strip when the gun was not being fired. The anvil between the guides had a radius of approximately 500 mm. This was because forming against a flat base would have been relatively ineffective. Standard hardness tests carried out on sectioned specimens of the needles gave a mean value of 586 HV_{20}.

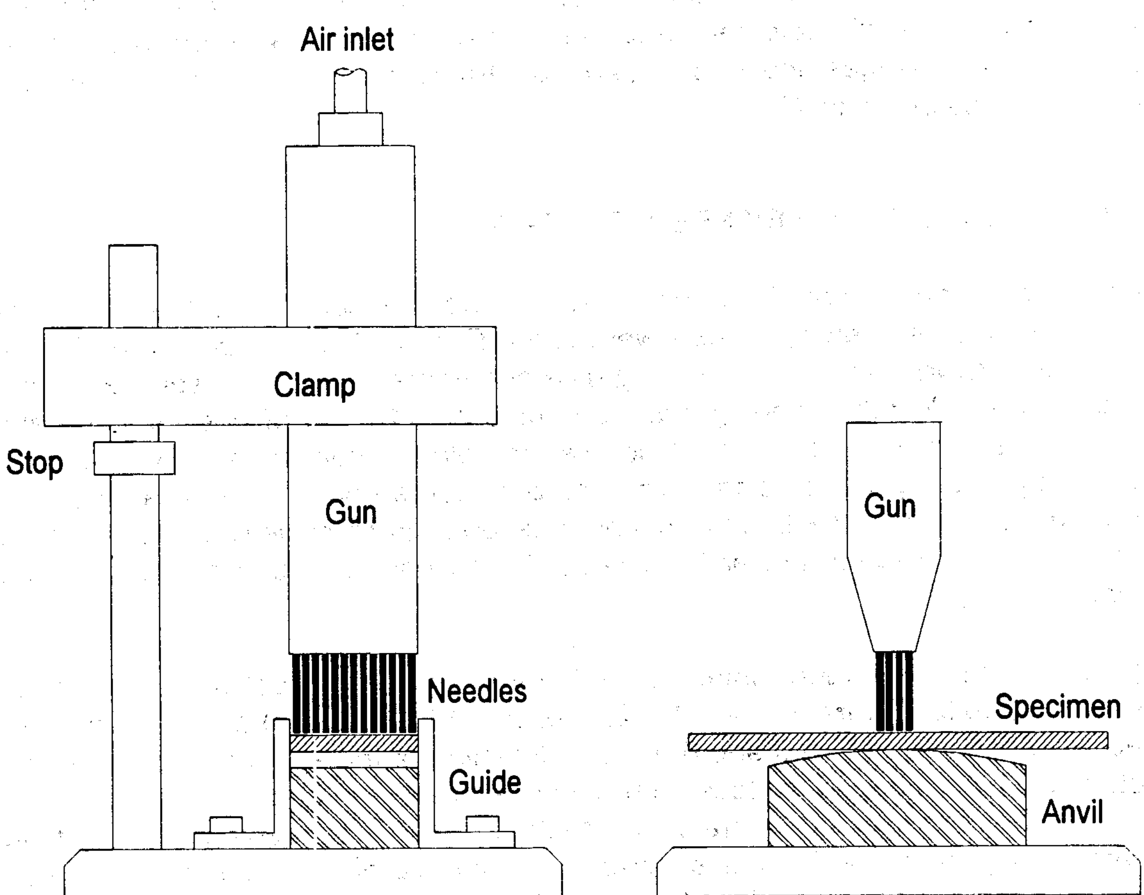

Fig.2 Schematic drawings of bench-mounted needle peening facility.

SHOT PEENING EQUIPMENT

Shot peening experiments were carried out using a laboratory shot peening facility based on a 20 h.p. twin-cylinder air-compressor feeding air through a drier and a pressure regulator to a suction-feed peening gun mounted inside a 1 m^3 cabinet. The supply of S170 cast steel shot was regulated using a 'Magnavalve'. Air pressure was monitored continuously at the actual gun with signals of shot supply rate and air pressure being fed to a multi-pen chart recorder.

RESIDUAL STRESS DEVELOPMENT

Residual stress measurements on peened surfaces were made using a standard two-exposure X-ray diffractometry technique. Chromium K_α radiation was used to detect angular changes, induced by residual strains, for the 211 ferrite diffraction line at ψ values of 0 and 45^0.

CURVATURES INDUCED BY NEEDLE PEENING

These experiments were designed to investigate the curvatures that could be induced by needle peening. Tests were carried out on 220 mm lengths of 40 mm wide bright-drawn mild steel strip using different air pressures to power the needle peening gun. Needle peening was performed on 110 mm of one face of each strip with the remaining 110 mm being used to hold the specimen. Peening was effected by passing the strip forwards and backwards under the gun after it had been remotely activated with a pre-set air pressure. Each cycle was timed to take 5 seconds. A device similar to a large Almen gauge was used to measure curvature.

Fig.3 shows the curvatures obtained for 3.0 mm thick mild steel strip specimens needle peened for different times (10, 20, 40, 80, 160 and 240 s) at one or other of three air pressures (4.0, 5.0 and 6.0 bar). Peening of the surface causes plastic stretching of the peened surface with a corresponding induced bending. The general shapes of each curve are similar to the familiar shot peening intensity/time curves. As needle peening times increase the surface of the steel strip becomes more and more heavily cold-worked and therefore more difficult to plastically deform. The effect of air pressure is interesting. Low air pressures are ineffective but higher pressures give similar rates of forming.

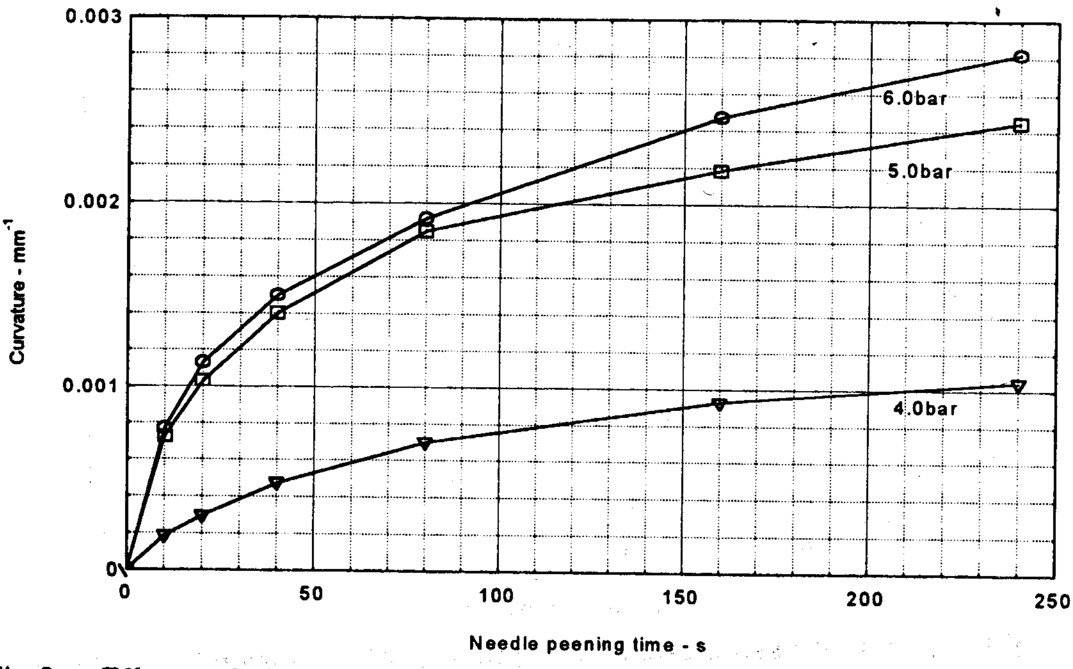

Fig.3 Effects of air pressure and needle peening time on curvatures induced in 3mm thick mild steel strip.

Fig.5 shows the curvatures obtained for 6.0 mm thick mild steel strip specimens needle peened at one or other of two air pressures (5.0 and 6.0 bar). As would be expected the induced curvatures are very much smaller than those observed for the 3.0 mm thick specimens. The shapes of the curves are very similar for both thicknesses of material with the higher gun air pressure giving rather more rapid forming rates. The effects of strip thickness are depicted in Fig.4.

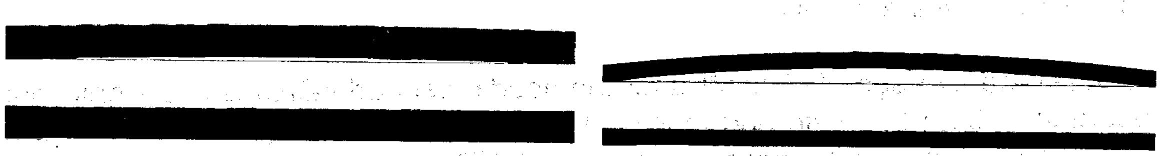

Fig.4 Pictorial representation of maximum curvatures obtained for 110 mm lengths of 6 mm and 3 mm thicknesses of steel respectively.

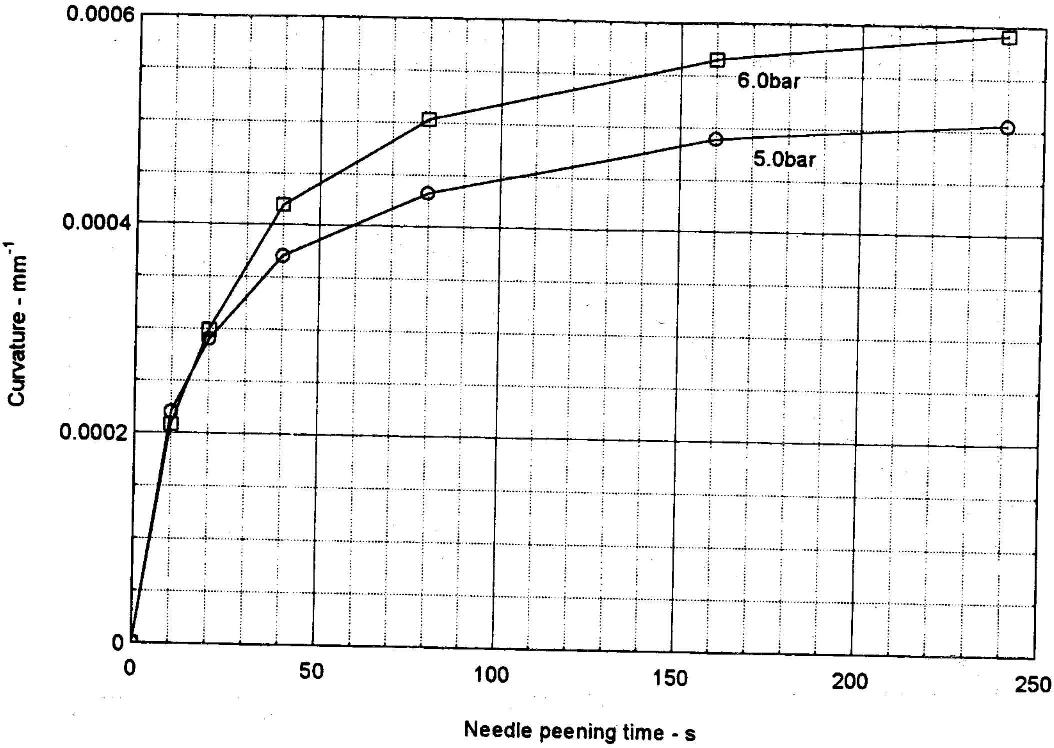

Fig.5 Effects of air pressure and needle peening time on curvatures induced in 6 mm thick mild steel strip.

SURFACE RESIDUAL STRESSES INDUCED BY PEENING.

X-ray surface residual stress measurements were carried out, by the author, on a variety of needle peened and shot peened annealed mild steel samples. All of the samples arose from an undergraduate research project being carried out under the author's supervision. The residual stress measurements are given in Tables 1 and 2. It may be noted that all of the values are negative which indicates compressive residual stress.

The observed average of -200 MPa for the needle peened samples is a significant proportion of both the yield and tensile strengths of mild steel (300 and 465 MPa respectively). An even higher proportion, -251 MPa, was obtained for the average of the shot peened samples.

Table 1 X-ray surface residual stress measurements on needle-peened annealed mild steel strip specimens.

Needle Type	Peening Time- s	Residual Stress - MPa
Flat-ended, 2 mm diameter	40	-219
	70	-139
	140	-203
Point-ended, 3 mm diameter	50	-200
	85	-199
	180	-241
		Mean = -200

Table 2 X-ray surface residual stress measurements on shot-peened annealed mild steel strip specimens peened with S170 steel shot..

Conditions		Residual Stress - MPa
	Peening time - s	
165 mm stand-off, 3.45 bar	5	-177
	20	-267
	60	-267
	Stand-off distance - mm	
20 s peening time, 3.45 bar	120	-266
	165	-271
	295	-256
		Mean = -251

DISCUSSION

Substantial curvatures have been obtained using needle peening with radii approaching 400 mm and 1600 mm for 3 mm and 6 mm thick steel respectively. Curvature increase with time has been found to be similar to that observed for shot peening by Kopp *et al* (2). The curvature obtained for a given needle peening treatment is inversely proportional to the square of the thickness of the strip being peened. This is because the induced bending moment is directly proportional to the thickness whereas the rigidity is inversely proportional to the cube of the thickness. Hence the maximum curvature obtained for the 3 mm thick strip was some four times as great as that obtained for 6 mm thick strip. Needle peening against a singly-curved anvil virtually restricted the curvature to one plane. Future work will investigate the effects of different radii and geometries of peening anvil and of material being peened. The residual stress measurements have shown that very useful levels of surface compressive stress can be induced by needle peening. Flat-ended needles produce much smaller indentations than spherical shot of a similar diameter and induce a polishing rather than a roughening effect. It may be concluded that needle peening could have useful commercial applications for both residual stress development and peen forming. With the present limited state of needle peening science it is probable that this should be restricted to less critical components than those that require precision shot peening.

REFERENCES

1 Reccius H, Endemann D and Hornauer KP, *Sheet Forming by Producing the Coverage with a Simultaneous Working System of Balls,* Proceedings of the Fifth International Conference on Shot Peening, 207-220, Oxford, 1993.

2 Kopp R, Wüsterfeld F and Linnemann W, *High Precision Shot Peen Forming,* ibid. *127-138.*

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