EFFECT OF SHOT PEENING ON THE FATIGUE LIFE OF AXIALLY LOADED NOTCHED COMPONENTS

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ABSTRACT

This investigation examines the effects of shot-peening upon the fatigue life of notched laboratory samples subjected to axial cyclic loading. The material used in this study is a 7075-T73511 Aluminium-Zinc alloy. The tests involved assessing the fatigue life of the material in the as-machined and peened conditions at room temperature. Four specimen types have been used with different geometries characterized by a range of stress concentrations and stress gradients. The experimental data provides strong evidence of the beneficial effects of the peening treatment upon the fatigue life of components subjected to tension-tension loading. The extent of life improvement has been found to be a function of the stress concentration factor.

KEYWORDS: Shot peening, Fatigue Life, Notched Components, Axial Loading.

INTRODUCTION

Shot peening is a well established cold working process, widely used by the automotive and aircraft industries, as compressive residual stresses induced by the process have been found to profoundly affect the fatigue fracture behaviour of metallic components. The literature contains numerous studies investigating the fatigue performance of shot peened components, many of which are included in the proceedings of the four international conferences that have taken place in the last 12 years (1-4). For general review of the process, reference can be made to (5-7).

The fatigue improvement is accomplished by the bombardment of the surface with spherical media (steel shots, glass beads, ceramic shots), under controlled conditions. Generally speaking, a number of surface treatments are available; thermal or thermochemical such as carburizing, nitriding, induction hardening; and mechanical surface treatments such as cold rolling, grinding, polishing to mention but a few, which are in competition with shot peening. Treatments of thermal and thermochemical nature have a limited applicability as they appear to discriminate on the material type. Mechanical treatments, on the other hand, do not discriminate on material types but their short comings are in terms of component geometry and shape. Shot peening is by far the most versatile process as it is highly adaptable to shape and size and characterized by high productivity, lower equipment capital investment, and lower energy costs.

The justification for the present study lies in the fact that reported information from previous studies (8-13) remains unclear as to whether the peening of metallic components subjected to axial loading is beneficial or detrimental. These inconsistent reports obviously do not provide the high level of confidence required for the industrial adaptation of the process to axially loaded components. Therefore, this study attempts to provide more information on the matter by adding further data emphasizing the effects of peening in the presence of a range of stress concentrations.

EXPERIMENTAL ANALYSIS

The material

The material used in this investigation is an Aluminium-Zinc 7075 alloy, tested in the T73511 condition, i.e. overaged for optimum stress corrosion resistance and given a controlled plastic deformation (1-3%) to reduce prior residual stresses. The material was supplied in an extruded bar form with a 31.75mm (1.25") diameter. The chemical composition and mechanical properties of the material are given in Table 1.

Table 1 Mechanical Properties and Chemical Composition by Weight of the Tested Material.

Mechanical Properties	σ_y 0.2% (MPa)			σ_{uts} (MPa)		ε_f (%)		Hardness (HB)		
	488			545		10.5		150-155		
Chemical Composition (%)	Al	Zn	Mg	Cu	Cr	Fe	Si	Ti	Zr	Mn
	Bal.	5.96	2.39	1.29	0.19	0.17	0.09	0.05	0.04	0.04

Selection of specimen configurations

The specimen design was based upon the guidelines of the BS 3518 part 3, and ASTM E466-82 specifications. In order to establish suitable configurations for the research programme, Finite Element methods were utilised to facilitate the evaluation of the stress concentration factors and stress gradients for a number of geometries. A typical finite element model used in this part of the study is shown in Fig.1. The model discretization and analysis of results were carried out using the SDRC-Ideas interactive pre-, post-processor, and the PAFEC finite element package was utilised for the static elastic analysis. A quarter of each geometry was used as exhibited biaxial symmetry was taken into account.

A wide range of candidate configurations were examined and finally four geometries with rectangular cross sections were selected for the study. The stress concentration factors associated with these geometries vary between 1.98 and 4.93, and a graphical representation of the stress distributions in the vicinity of the notches is shown in Fig.2. Details of the selected notch configurations are depicted in Fig.3.

It has been established that high machining roughness is associated with high magnitude surface tensile residual stresses, Rasul (14). As the surface roughness is related to the feed rates used, the specimens for this study were carefully machined aiming to minimise the magnitude of machining induced tensile residual stresses. The surface roughness of the specimens was better than 1.5 μm CLA and was achieved by using CNC machining and the input is detailed in the Appendix.

Specimen peening

The specimens were surface treated in house using a direct pressure blasting cabinet manufactured by Vacu-Blast Ltd., England. For the purpose of the investigation, S230 steel shot, having a mean diameter of 0.6mm (0.023") was employed. With the aid of a micro-hardness test facility, it was possible to establish the hardness of the shot which was found to be 630H_V on average. The peening of the specimens was carried out whilst rotated under the shot stream with a rotational speed of 20 rpm. The nozzle stand off distance was set to 140mm and the delivery pressure was adjusted to 103.4 KPa (15psi). The coverage was examined with a ten power magnifying glass in conjunction with a fluorescent tracer spray and an ultraviolet light illumination system. The peening coverage achieved was 150% and the intensity was evaluated in accordance to the MIL specification (15) to be 0.36mm (0.014") measured with a standard 'A' Almen strip, the saturation curve for the peening operation is shown in Fig.4.

Fatigue testing

The experimental work consisted of preliminary and main test programmes. The test programme was carried out utilising a 100KN uniaxial servo-hydraulic test machine. The preliminary investigations concentrated on establishing base line information regarding the fatigue life of the material. Test specimens in the as- machined condition were used for the determination of the σ_a- N curves for the four notched geometric configurations. In the main part of the programme shot peened specimens were utilised and σ_a- N curves were determined with the view of examining the effects on fatigue life due to shot peening in the presence of alternating stress σ_a. All tests were performed at room temperature and the load frequency selected for the programme was 25.0 Hz. Constant amplitude tension-tension loading was used where the load ratio R was maintained to a value of 0.04 for all the tests performed. Attention was devoted in selecting appropriate load ranges where the specimens were subjected to elastic loading conditions in the high cycle fatigue regime.

ANALYSIS OF RESULTS AND DISCUSSIONS

Preliminary tests on the effect of shot peening showed no improvement in fatigue life over the as-machined specimens and in many cases it was found that the effects of peening were detrimental. Some typical results are shown in Table 2 where, the fatigue life was reduced by 17%. This was accounted for by the fact that corner cracks were developed at the notch edges of the specimens due to the chipping of these corners by the shots, which was detected with a ten power magnifying glass. These corner cracks, of course, have caused pre-mature failures and reduced the fatigue life of the peened specimens. This problem was overcome by giving a light edge finish at the notch corners using 800 grit paper before the peening treatment, which is believed to allow uniform distribution of the compressive residual stresses over the entire surface of the specimen and prevented the chipping of the notch corners.

Table 2 Fatigue Life of Specimen 1 at an Applied Stress Range of 233 MPa.

Number of Cycles to Failure ($x10^5$)					
As-Machined		Shot-Peened (No edge trim)		Shot-Peened (With edge trim)	
1.510		1.514		4.763	
1.784	Average	2.328	Average	2.426	Average
3.102	2.155	1.653	1.792	3.626	3.696
2.223		1.674		3.970	

In order to check the uniformity of the peening treatment and measure the surface roughness of the specimens, a Talysurf 4 profile-tracing instrument (16) has been used. It incorporates an automatically controlled three-dimensional relocating stage, as well as a microcomputer-based data handling processing facilities. A three dimensional view of the surface appearance of a peened specimen is shown in Fig.5, which confirm the uniformity of the surface roughness. The average surface roughness of three shot peened and two as-machined specimens were measured to be 8.3 and 1.4 μm (CLA) respectively.

Fatigue testing to failure was performed at an applied stress ranging from 34% to 62% of the yield stress, giving fatigue lives between 10^5 to 10^6 cycles. The testing was terminated between $1.5x10^6$ to $3.0x10^6$ cycles, if failure did not occur.

The results of these tests are presented as S-N curves, Fig.6. These curves are visually fitted through median points and thus represent 50% of expected failures. It can be noted that the improvements due to peening in the fatigue life of the four specimens are at all load levels and gradually increases as the load level decreases. The improvement is a function of the stress concentration factor, and increases as the stress concentration increases. The improvements as compared to 10^5 cycles to failure of the as-machined specimens varies from 40% for specimen 1 to 220% for specimen 4.

Table 3 gives an estimate of percentage enhancement in fatigue strength at 10^6 cycles for the four notch geometries tested, which indicates the beneficial effect of shot peening on notched components that must be considered in the design of critical parts.

Table 3 Estimates of Percentage Improvement in Fatigue Strength at 10^6 Cycles

Notch Geometry	Stress Concentration Factor	Fatigue Strength at 10^6 Cycles (MPa)		Gain (%)
		As Machined	Shot Peened	
Notch 1	1.98	218	224	2.7
Notch 2	3.19	252	260.5	3.4
Notch 3	4.29	173.5	185	6.6
Notch 4	4.93	168	188	11.9

CONCLUSION

The effect of shot peening on fatigue life of the 7075-T73511 Aluminium-Zinc alloy was studied under tension-tension fatigue loading condition for four different notch geometries featuring a range of stress concentrations. The results show that shot peening can be applied to increase the fatigue life (i.e. endurance limit) of the tested material subjected to axial loading. The beneficial effect of the process is greater at long fatigue lives than at short fatigue lives, and further the beneficial effects of peening are far greater on notched parts with high stress concentration than on parts with lower stress concentration. This improvement was achieved by giving a light edge finish at the notch corners before the peening treatment in order to eliminate the chipping of the edges, which was identified to be responsible for premature failures. Evidently, the shot peening has produced repeatable results indicating improvement in the fatigue life over the range of loads and geometric configurations utilised.

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APPENDIX: Machining Details of the Fatigue Specimens.

TURNING CENTRE:
(SPEEDS = SURFACE SPEED METRIC, FEEDS = METRIC PER REV, MAX SPEED 4500 RPM)

FIRST OPERATION >
FACE END ROUGH TURN 0.875 DIA (SPEED 300/FEED 0.25), CENTRE DRILL (SPEED 2000 RPM/FEED 0.02), FINISH TURN 0.875 DIA (SPEED 400/FEED 0.1)

SECOND OPERATION >
FACE END TO LENGTH (SPEED 400/FEED 0.1), CENTRE DRILL (SPEED 2000 RPM/FEED 0.02), ROUGH TURN DIA 0.875 & 19.0 M/M (SPEED 300/FEED 0.25), FINISH TURN DIA 0.875 & 19.0 M/M (SPEED 400/FEED 0.1), SCREW CUT ONE END (SPEED 1000 RPM/FEED 1.814 M/M)

THIRD OPERATION >
SCREW CUT OTHER END (SPEED 1000 RPM/FEED 1.814 M/M)

MACHINING CENTRE:
TOOL 1
18 M/M RIPPER CUTTER, SPEED = 600 RPM, FEED = 100 M/M PER/MIN
* ROUGH OUT 9 M/M WIDTH AND CUT OUTS *
TOOL 2
12 M/M E/MILL CUTTER, SPEED = 500 RPM, FEED = 100 M/M PER/MIN
* FIRST FINISH CUT *
TOOL 3
12 M/M E/MILL CUTTER, SPEED 360 RPM, FEED 40 M/M PER/MIN
* FINISH CUT TO SIZE *
** NOTCH 4 ONLY **
TOOL 4
6 M/M FC3 CUTTER, SPEED = 1000 RPM, FEED 100 M/M PER/MIN
* ROUGH OUT CUT OUTS *
TOOL 5
4 M/M FC3 CUTTER, SPEED = 1000 RPM, FEED 30 M/M PER/MIN
*FINISH CUT TO SIZE *

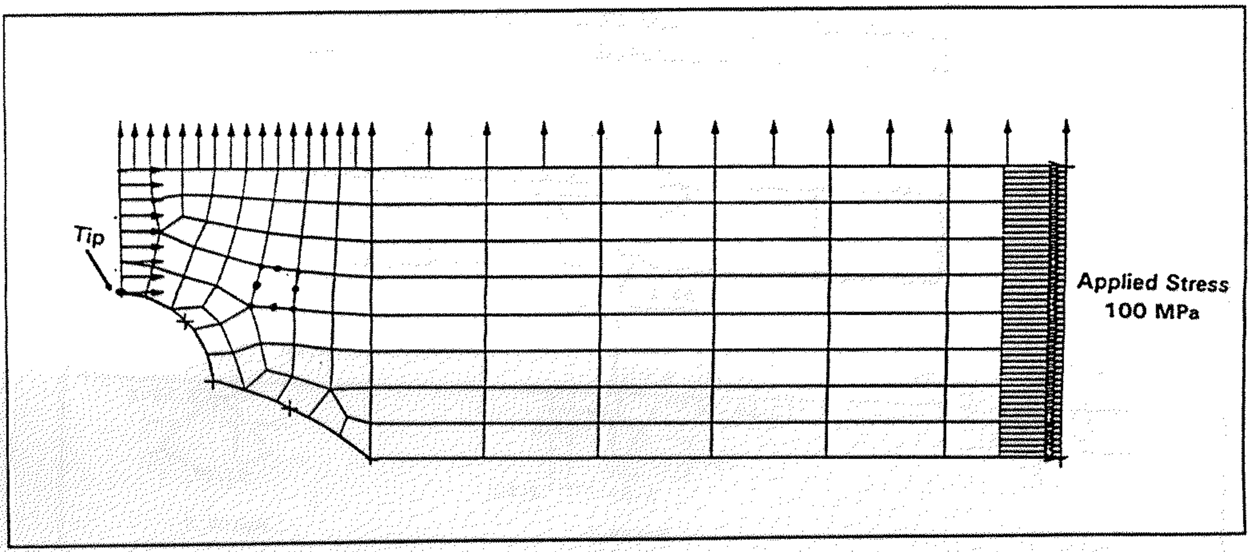

Fig.1 Finite Element Mesh Generated for Notch 3.

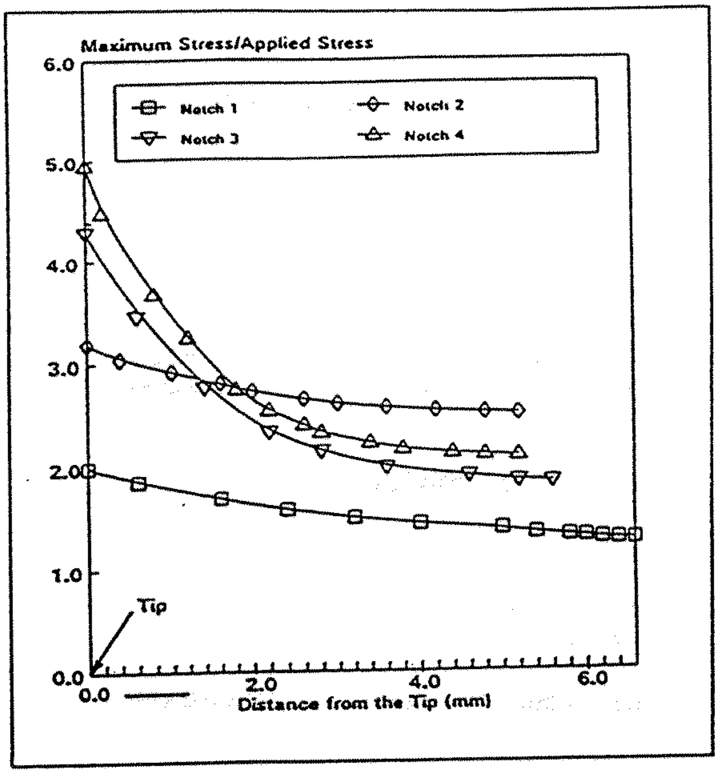

Fig. 2 Stress Distribution Across Half the X-Section of the Specimens.

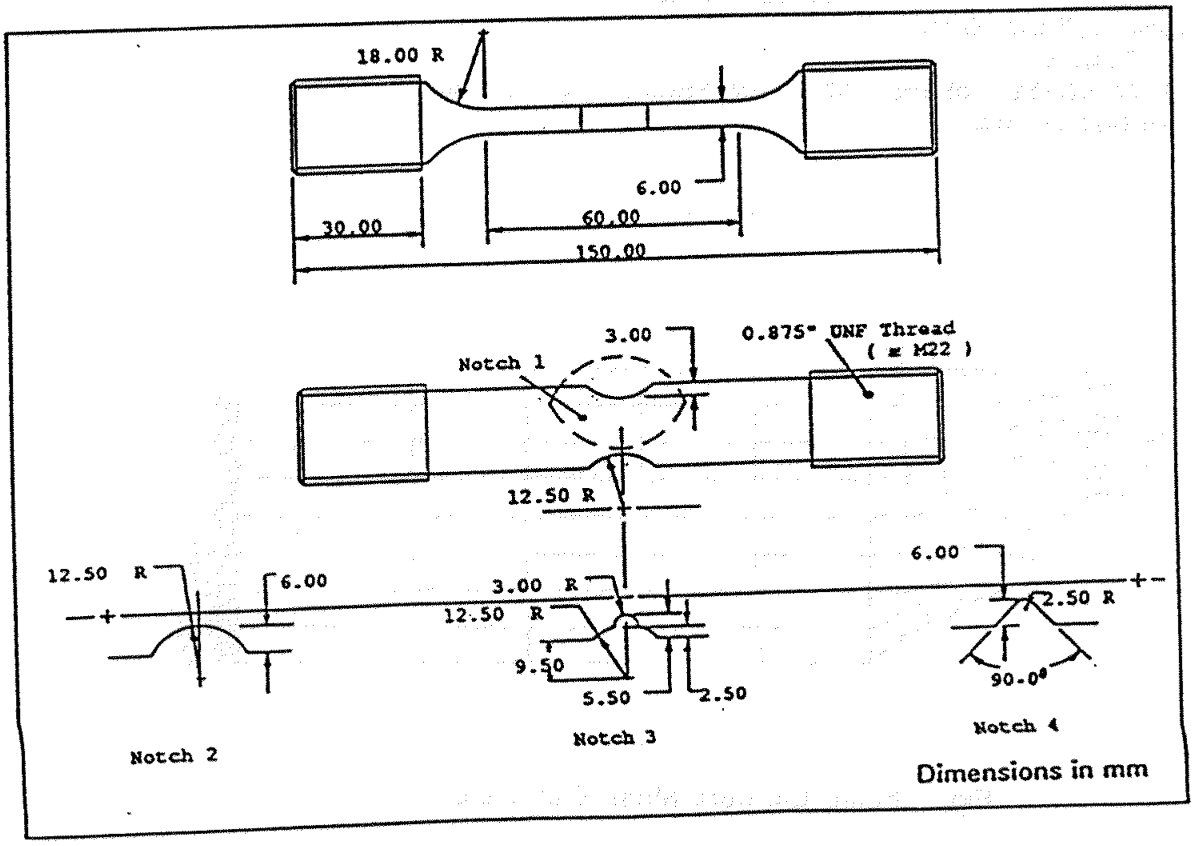

Fig. 3 Fatigue Specimen Geometries.

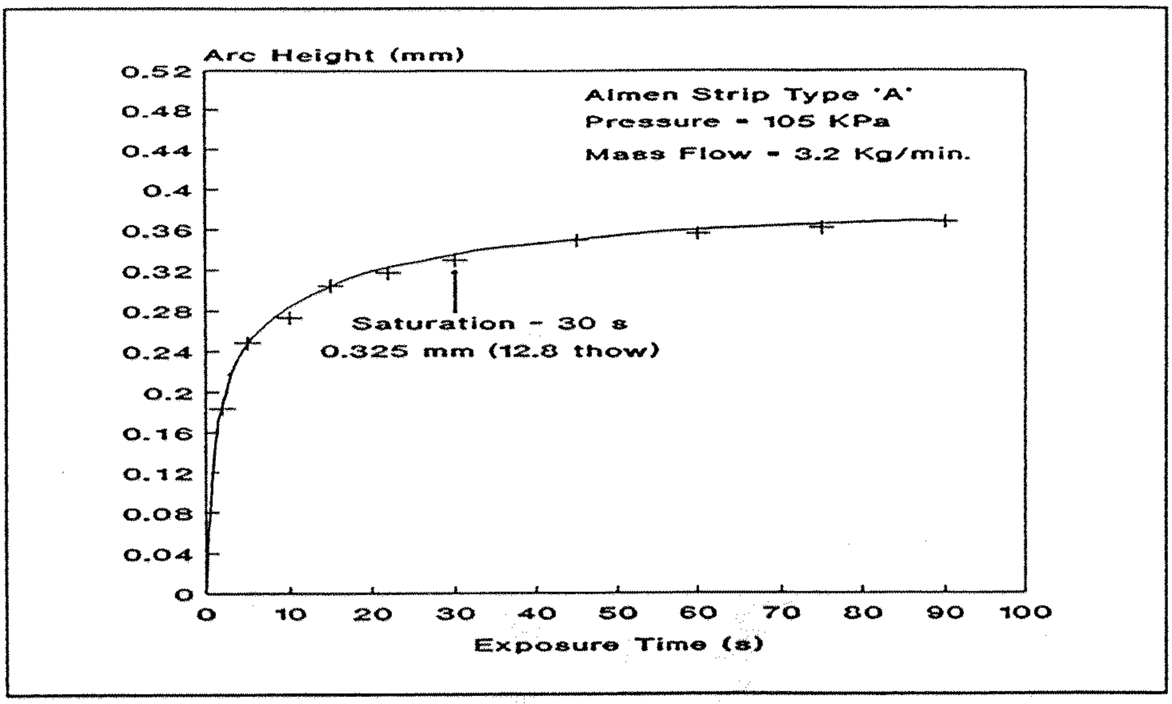

Fig. 4 Saturation Curve for the Shot Peening Operation.

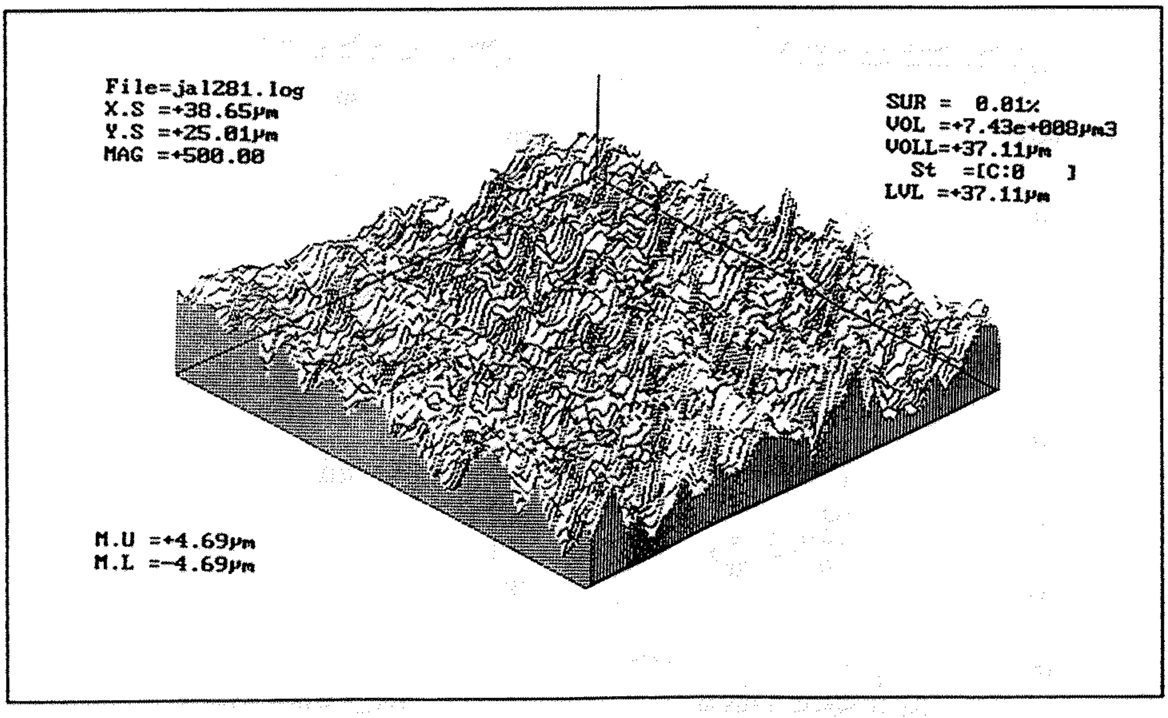

Fig. 5 3-D View of the Appearance of a Shot-Peened Specimen.

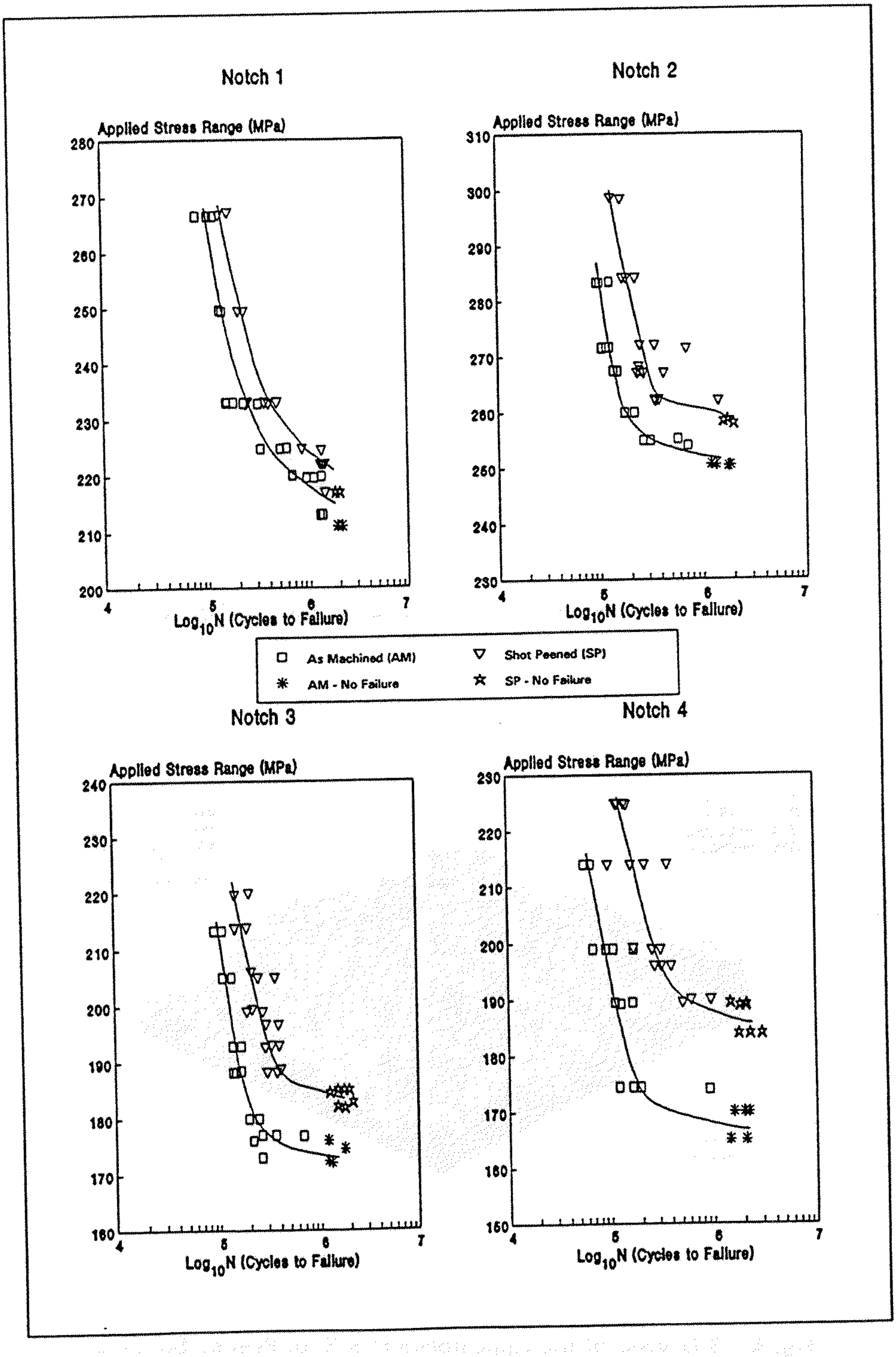

Fig. 6 S-N Curves for the Four Tested Specimen Geometries.