TRANSMISSION ELECTRON MICROSCOPY ANALYSIS OF SHOT PEENING STRENGTHENED LAYER FOR SOME INDUSTRIAL ALLOYS

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ABSTRACT

Substructure variation along the shot peened layer can clearly be observed by transmission electron microscopy (TEM) using layer by layer analysis and the cause of surface strengthening for shot peening can be explained. Experimental results are obtained as follows: 1) Microdeformation twin is the main substructure in the shot peening layer of α–brass or stainless steel: 2) Dislocation cell is the main substructure in the peened layer of low carbon steel; 3) Shot peening can not change the dislocation array in martensitic steels; 4) The array of surface substructure will greatly influence the residual stress distribution and the fatigue strength of relevant alloys.

KEYWORDS

Transmission electron microscopy, shot peening, microstructure, substructure, dislocation

INTRODUCTION

The bending fatigue strength of some alloys such as α–brass and stainless steel can be raised by shot peening but shot peening cannot influence the bending strength of other alloys such as annealed low carbon steel etc. This phenomenon is associated with the distribution and the relaxation of residual compressive stress in surface shot peened layer. If the residual stress does not relax in fatigue testing the bending fatigue strength of experimental materials will keep its value in a relative high level, otherwise the fatigue strength of the materials can not be improved by shot peening. In fact, the stability of the residual stress in fatigue process is directly influenced by the substructures of surface strengthened layer. In this paper five typical alloys were chosen for transmission electron microscopy analysis. The thin foils in strengthened layer were cut from on fatigue specimen surface sheet by sheet. Connecting TEM observation with the test of mechanical properties the relationship between substructure and the feature of strengthened layer could be explained.

EXPERIMENTAL PROCEDURE

The Chemical Composition and the Treating State of Experimental Alloys

The chemical composition (in wt%) of five tested alloys are listed as follows:
α–brass: Zn 31.5, Sb 0.0017, Bi 0.0019, As 0.002 and Cu balance.
Stainless steel (1Cr18Ni9Ti): C 0.12, Cr 19.1, Ni 9.5, Ti 0.83, Si 0.75, Mn 0.85, S 0.02, P 0.03.
Low carbon steel (1010): C 0.12, Si 0.34, Mn 0.45, S 0.03, P 0.03.
Low carbon martensitic steel (20Cr): C 0.19, Si 0.61, Mn 0.72, Cr 0.95, S 0.03, P 0.03.
High carbon martensitic steel (GCr15): C 0.79, Si 0.31, Mn 0.25, Cr 1.45, S 0.02, P 0.02.
α–brass was heated at 650 ℃ for 2hrs, then furnace cooling to room temperature; 1Cr18Ni9Ti steel was heated at 1050 ℃ then water cooling; 1010 steel was heated at 930 ℃ and furnace cooling to room temperature; 20Cr steel was quenched from 900 ℃ and GCr15 steel was quenched from 860 ℃ and tempered at 190 ℃ for 2hrs.

Shot Peening

Plate specimens (for tensile and bending fatigue test) with gauge section 40x20x5 mm were shot peened under following technical parameters: diameter of chilled iron shot was 0.5–0.8mm and the distance between specimen and spray nozzle was 80 mm. The spray pressure was 450 KPa.

Mechanical Properties

The mechanical properties of five experimental alloys were listed in table 1.

Tab.1 Mechanical Properties of Tested Alloys

Alloy	σ_S MPa	σ_b MPa	Hardness	σ_{MAX} *** (or σ_{-1})MPa Before S.P.	After S.P.
α–brass	91	310	125(HB)	90(R = −1)	130(R = −1)
1Cr18Ni9Ti	328	795	187(HB)	310(R = −0.4)	467(R = −0.5)
1010	274	410	112(HB)	323(R = −0.4)	338(R = −0.5)
20Cr	1150	1580	47(HRc)	400(R = −1)**	710(R = −1)**
GCr15	----	2700*	62(HRc)	360(R = −1)**	650(R = −1)**

* σ_{bb} bending strength, ** rod specimen, *** bending fatigue strength

TEM Analysis

Figure 1–5 have shown the TEM microstructures of the surface strengthened layer for five alloys. Thin foils for TEM observation were cut from on the specimen surface layer by layer, so that the substructure in strengthened area can be clearly identified. TEM analysis was carried out on a JEM–200CX transmission electron microscope.

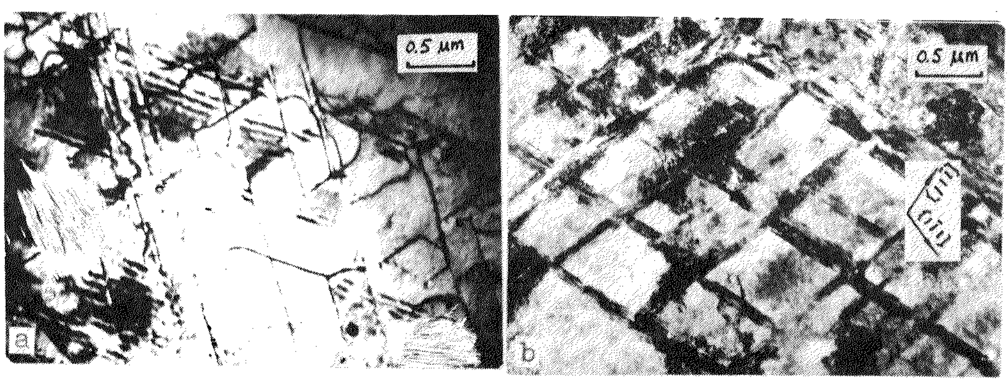

Fig.1 TEM micrographs of α–brass, 0.03mm beneath the specimen surface, (a) before shot peening, B = [011] and (b) after shot peening, B = [011]

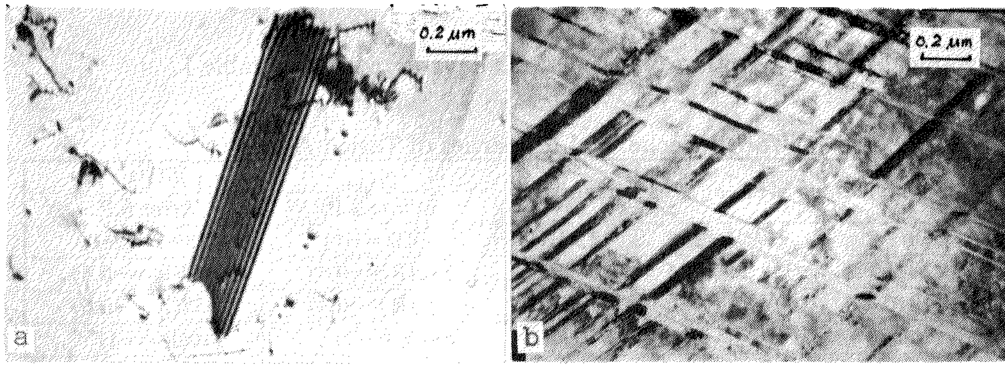

Fig.2 TEM micrographs of 1Cr18Ni9Ti steel, 0.03mm beneath the specimen surface, (a) before shot peening, B = [111] and (b) after shot peening, B [011]

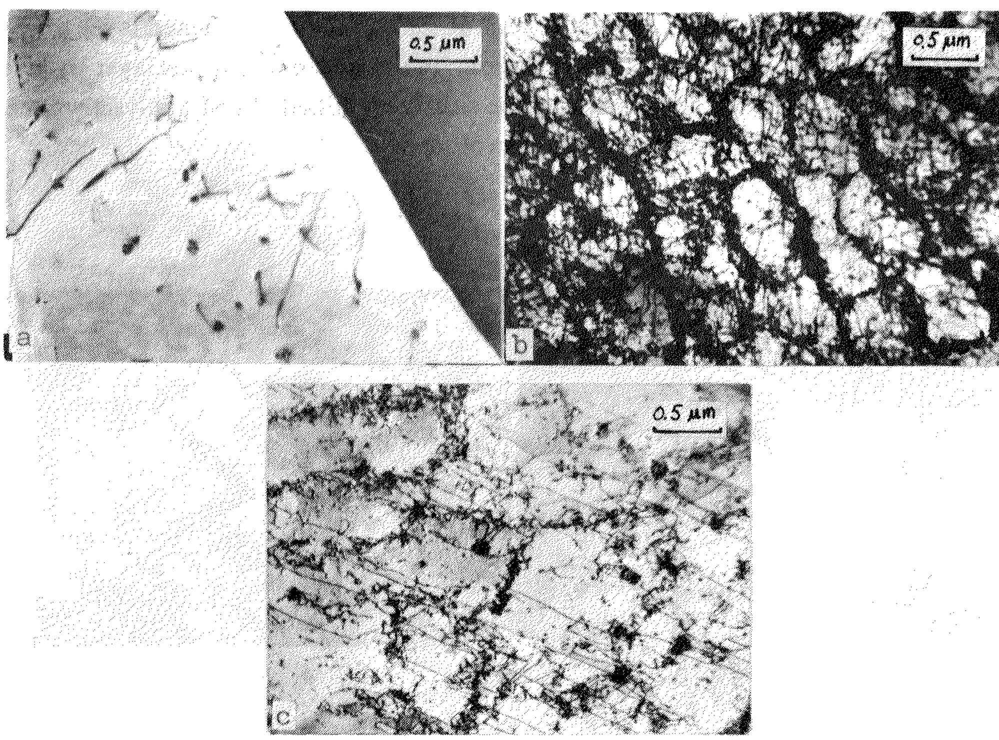

Fig.3 TEM micrographs of 1010 steel, 0.03mm beneath the specimen surface, (a) before shot peening, B = [112], (b) after shot peening, B = [011] and (c) shot peening and fatigue at σ_{max} = 340 MPa for $5x10^5$ cycles, B = [011]

Fig.4 TEM micrograph of 20Cr low carbon martensitic steel, 0.03 mm beneath the specimen surface, B = [111]

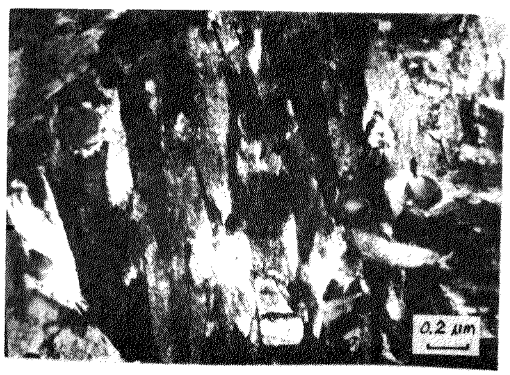

Fig.5 TEM micrograph of GCr15 high carbon martensitic steel, 0.03mm beneath the specimen surface, B = [100]

RESULTS AND DISCUSSION

F.C.C. Alloys

The substructure variation of α–brass in surface strengthened layer before and after shot peening were shown in Fig.1. Before shot peening the microstructure of annealed α–brass consists of homogeneous polygonal α grains. There are some linear dislocations within the crystal. The density of dislocation is relatively low.Because of the low stacking fault energy of α–brass (about $20 erg/cm^2$) stacking faults can also be found in the local area of a grain, Figure 1 (a). After shot peening microdeformation twins in basketweave pattern will introduce into surface strengthened layer. The twin plane of f.c.c alloy is part of {111} plane. In

Figure 1 (b) two sets of twin intersect each other. The twinplanes of them are $(11\bar{1})$ and $(1\bar{1}1)$ respectively. Figure 1 (b).Near the outsurface the twin density is very high. Beneath the specimen surface with the increase of layer depth twin density decreases gradually. When the depth exceeds 0.3mm, no deformation twin can be observed in the layer.

1Cr18Ni9Ti steel has low stacking fault energy also (15–20 erg / cm^2). After shot peening the array of microdeformation twins is the same as that in α–brass. The change of substructure before and after shot peening was shown in Figure 2 (a), (b). The length and width of twin in 1Cr18Ni9Ti steel are smaller than that in α–brass due to the high strength (σ_s, σ_b) and strengthening exponential (n) of stainless steel.

The deformation twins in α–brass and 1Cr18Ni9Ti steel arrange in a paling form [1]. The twin paling is a stable substructure. When the specimen was fatigued under repeat load the morphology of the paling might not change. Because each net in the paling is more or less the same as a structural unit and no plastic deformation will take place in the unit, therefore not only the twin paling can bear higher norminal repeat load but can prevent the residual stress from relaxation. Twin paling also act as obstacle which can obstruct microslip towards the outface, thus the nucleation of the fatigue crack at specimen surface will be inhibited.

Experimental results have shown that after shot peening the bending fatigue strength of α–brass and 1Cr18Ni9Ti steel have increased by 44% and 51%respectively over that before shot peening and the residual compressive stress on the surface can still keep its original value after 10^6 cycles loading [2][3].

Low Carbon Steel (1010)

The microstructure of annealed 1010 steel consists polygonal ferrites with a little amount of pearlites. Dislocation density in ferrite is quite low (about $10^7 cm^{-2}$). Major part of dislocations are linear, Figure 3 (a). After shot peening dislocation density increases markedly. Linear dislocation change into cell structure through cross slip process, Figure 3 (b). The average diameter of dislocation cells increases with the increase of the layer depth. When the specimen shot peened is undergone repeat loading (σ_{max}= 340 MPa) for $5x10^5$ cycles, the cell structure in the surface layer tends to loose, Figure 3(c). Comparing with the twin paling cell structure is not a stable substructure under fatigue load. Cell structure cannot create a effective obstacle to stop the nucleation of fatigue crack and cannot prevent residual stress from relaxation. The strengthening effect and the residual compressive stress caused by shot peening tend downwards owing to the local plastic deformation (dislocation movement) in ferrite which results in the increase of cell diameter and relexation of residual stress, consequently shot peening cannot improve the bending fatigue strength of 1010 steel, see Table 1. Residual stress measurement provides relevant result. When shot peened specimen fatigued at σ_{max}= 340 MPa for $5x10^5$cycles, the residual compressive stress drops from –350 MPa to –210 MPa.

Martensitic Steel

Fig.4 and Fig.5 are the micrographs of 20Cr and GCr15 steel after shot peening. These TEM microstructures are similar to those before shot peening. For the original dislocation density of 20Cr andGCr15 steel is rather high ($\geqslant 10^{12}cm^{-2}$), the additional dislocation caused by shot peening cannot be resolved by transmission electron microscope, so that TEM analysis will not distinguish the difference between the microstructures before or after shot peening [4]. After shot peening the bending fatigue strengths of 20Cr and GCr15 steel increase obviously. The raise of bending fatigue strength is correlative to following factors: the increase of dislocation density; the high resistance of local plastic deformation of martensitic matrix; the influence of fine carbides and retained austenites. In a word this is a complicated problem to be further investigated.

CONCLUSION

Microdeformation twin is the main substurcture in the shot peened layer of α−brass and 1Cr18Ni9Ti steel. Microtwin paling not only can obstruct the local plastic deformation of surface layer but prevent residual stress from relexation in fatigue testing, so that micotwin is a stable substructure. Dislocation cell is the main substructure in shot peened layer of 1010 steel. Dislocation cell is not a stable substructure in fatigue testing. Shot peening does not improve the bending fatigue strength of annealed 1010 steel. Shot peening cannot chang the dislocation array in martensitic steels because of the high original dislocation density in martensitic crystal. The array of surface substructure will greatly influence the residual stress distribution and the fatigue strength of investigated alloys.

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