THE ROLE OF TEXTURE ON PRESTRAIN EMBRITTLEMENT IN ARMCO IRON

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INTRODUCTION

The ductility of wrought materials can be strongly influenced by their processing history. A number of prior studies have shown that compressive straining of many materials results in an anisotropic reduction in the tensile ductility of the wrought product. Among the metals studied previously are Bessemer steel, open hearth steel, cast steel, 60-40 brass [1,2], high purity iron [3], rimmed E-steel [4-8], and 1014 steel [9]. The mechanisms by which this prestrain embrittlement occurs have never been established. The work reported here is part of a broad investigation undertaken to identify these mechanisms.

The prestraining technique most commonly used in these earlier embrittlement studies was uniaxial compression of cylinders. Height reductions of greater than 50 percent frequently resulted in a subsequent reduction in area of less than 3 percent for specimens tested in tension in the direction of initial prestrain [1]. Although the degree of embrittlement increased with the amount of prestrain for specimens tested in the prestrain direction, those tested in the transverse directions retained much of their original ductility for prestrains as high as 85 percent height reduction thus demonstrating the marked anisotropy of prestrain embrittlement [2]. In addition to the uniaxial compression of cylinders, the rolling of rods [3] and the bending of bars [4-6] have also been successfully used to cause prestrain embrittlement.

In an extensive study of ship steels, Mylonas and coworkers [4-8] found that for various combinations of temperature and method of introducing compressive prestrain, there was a critical strain below which high ductility was retained and above which the material fractured with low ductility during subsequent tensile testing. This narrowly defined critical compressive prestrain was called the "exhaustion limit".

Korber, et al suggested that fibering and texture changes resulting from compressive prestraining (of several different metals) might be possible causes for at least part of the subsequent loss of tensile ductility [1,2]. Based on more recent phenomenological observations, however, it can be concluded that the mechanisms of prestrain embrittlement are other than the mechanical fibering that lowers the transverse properties of hot rolled sheet and plate.

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EXPERIMENTAL PROCEDURE

The material used for this study was commercial Armco ingot iron bar with the following reported composition in weight percent: C, 0.006; Cu, 0.095; Mn, 0.062; Si, 0.02; S, 0.016; P, 0.006. Prestrain blanks were machined from the 38 mm diameter bars as nearly full-size right circular cylinders. Different H/W ratios had to be used in order that reasonably-sized longitudinal tensile specimens could be obtained from the flattened cylinders after large prestrains. It was established that cylinders with H/W ratios as large as two could be uniaxially homogeneously compressed without incurring any instability. The flat ends of all cylinders were faced-off in a lathe and polished to a 25 μm surface finish to minimize frictional end constraints resulting from platen-specimen interface contact during prestraining.

Homogeneous prestraining was accomplished using a jig with polished hardened steel platens. Nominally 125 μm thick sheets of teflon were inserted between the ends of each cylinder and the platens to act as a lubricating film. No barreling or wrap-around of free surface material onto the contact surface was observed after prestrain, indicating that compression was homogeneous. The states of stress and strain were nearly uniform through the cylinder; consequently any structural damage or textural changes developed by prestraining should also be evenly distributed and reproducible. Prestrains were applied incrementally, the principal reason being the need to replace the teflon sheets at the specimen-platen interfaces periodically. It was also necessary to re-turn the cylinders frequently during the stepwise prestraining to maintain a circular cross section and assure stress state uniformity. When strained, the Armco iron cylinders deformed nonuniformly displaying an axisymmetric four fold symmetry. Finally, it was occasionally necessary to reduce the cross section of cylinders when the maximum capacity of the press was reached in order that additional prestrain could be developed. Thus, each cylinder was alternately prestrained and machined until the desired amount of compressive prestrain deformation was accumulated.

After prestraining in the longitudinal direction two sets of smooth and notched round bar tensile specimens were then removed from the cylinders with axes in either the longitudinal or transverse direction. Smooth bar specimens had a 9.5 mm gage length and a 3.2 mm diameter. Notched bar specimens were 8.5 mm in diameter with circumferential notches 1 mm deep and having a root radius of 50 μm. Care was taken to avoid heating these tensile specimens during machining to preclude any possible thermally induced structural changes. Tensile testing was performed on an Instron testing machine at room temperature at a cross-head rate of 2.5 mm per minute. The dimensions of the necked region of each fractured tensile specimen were measured on a toolmaker's microscope. Yield strength, ultimate tensile strength, and reduction in area were determined for each specimen. The reduction in area was used as the measure of retained ductility because it is a highly structure-sensitive parameter.

RESULTS AND DISCUSSION

Longitudinal cylinders were homogeneously prestrained in the axial direction to as much as 83 percent height reduction prior to tensile testing. The ductility of both notched and unnotched specimens of unprestrained iron was higher in the longitudinal direction than in the transverse direction. The values were 84 percent R.A. and 76 percent R.A. respectively for smooth

bar specimens. For notched bar specimens the disparity was subtantially greater, 64 percent R. A. for longitudinal specimens compared with 28 percent for transverse specimens. This anisotropy in initial ductility is undoubtedly due to the fibrous nature of the distribution of oxides and other inclusions. Moreover, the retained ductility of longitudinal and transverse smooth bar tensile specimen was essentially unaffected by prestrains as great as 67 per cent. On the other hand, the ductility retained by notched specimens was severely affected by prestrain, as seen in Figure 1. It was reduced to zero percent R.A. after 62 percent prestrain for longitudinal specimens and for transverse specimens it was reduced to 2 percent after 83 percent prestrain.

As Korber, et al [2] had postulated earlier, either, or possibly both, textural or particle-related microstructural damage occurring during prestraining could be responsible for the embrittlement. Optical microscopic examination of the fracture surfaces of sectioned notched longitudinal tensile specimens showed that the fraction of these fracture surfaces consisting of cleavage facets increased and the fracture surface became more planar as the prestrain increased (cf. Figures 2a and 2b). In addition, the notched tensile specimen tested in the transverse direction after a prestrain of 83 percent failed with a large area of cleavage parallel to the tensile axis and connected to the notch root by regions of dimpled ductile fracture. Based on these observations it appeared that changes in texture such as to orient the {100} cleavage planes perpendicular to the compression direction might account for the anisotropic prestrain embrittlement observed in this material. Previously published texture studies support this theory [10,11]. The primary compression fiber texture of iron is known to be <111> with a <100> secondary fiber texture. Because the {100} plane is also the cleavage plane in iron, prestrain embrittlement could possibly be caused by the development of this strong fiber texture. The <200> fiber texture of cylinders with differing prestrains was therefore determined using a high speed Siemens texture goniometer and chromium radiation. An 85 degree pole figure consisting of 5,100 data points was automatically produced by the Schultz technique for each of a series of prestrained cylinders.

The texture analysis showed that after 42 percent uniaxial longitudinal prestrain a strong <200> fiber texture had developed which is not further increased significantly by prestraining to values as high as 67 percent. A comparison of the retained longitudinal ductility, Figure 1, with the pole figures showed that a strong <100> fiber texture had already developed prior to the appearance of prestrain embrittlement. The correlation of embrittlement with texture was sufficiently good, however, to indicate that texture development during prestraining does have a significant effect on retained ductility of Armco iron and probably in all those metals and alloys that exhibit cleavage failure under some conditions.

From a related phase of this program, strong evidence that microcracks are generated at inclusions during prestraining has also been obtained. To separate clearly the effects of texture and particle-related damage on retained ductility after prestraining, a critical series of tests was carried out in which the prestraining was done under hydrostatic pressure. Large hydrostatic compressive stresses during prestraining should effectively prevent the formation of voids and cracks [12] but at the same time should not affect texture development. Several longitudinal cylinders were uniaxially prestrained 67 percent under different levels of superimposed hydrostatic pressure prior to tensile testing. The pressures were in the range of 310 MPa to 414 MPa. When the superimposed hydrostatic pressure during prestraining was increased, the longitudinal fracture strength of notched bars in tension rose until it exceeded the yield strength, Figure 3; concurrently the retained ductility also increased substantially, Figure 4. Microstructural examination of the cylinders prestrained under pressure revealed that the normal microcrack formation was delayed by the superimposed pressure. Thus, the formation of matrix microcracks of sufficient length to nucleate premature cleavage fracture appears to be the primary mechanism responsible for prestrain embrittlement in Armco iron while the effect of textural changes, although probably a factor, is secondary.

SUMMARY

Commercial Armco iron has been found to exhibit anisotropic prestrain embrittlement as a result of room temperature compressive deformation. This effect was only observed with notched tensile specimens; smooth bar specimens suffered no embrittlement at least up to 67 percent prestrain. In subsequent longitudinal tensile tests the retained ductility drops with increasing prestrain until it is reduced to 0 after a prior 62 percent height reduction. When tested in the transverse direction, the ductility loss is much less severe for prestrains at least as great as 83 percent.

Texture analyses show that compressive prestraining causes the development of a strong <100> secondary fiber texture that preferentially orients the cleavage planes normal to the stress axis.

Prestraining under moderate pressures to make the hydrostatic component of the total stress compressive significantly reduces the normally observed prestrain embrittlement. This indicates that the contribution of texture to this form of embrittlement, if at all significant, is secondary to that of particle-induced voids and microcracks.

ACKNOWLEDGEMENT

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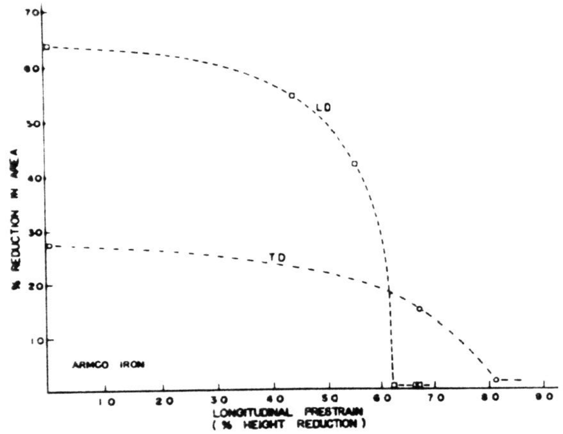
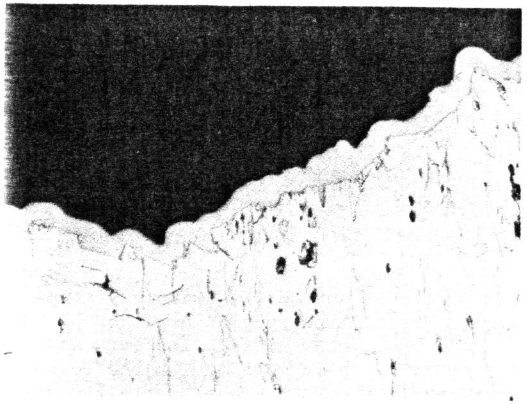
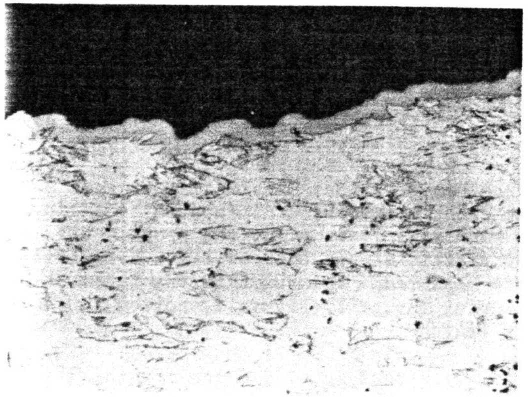


Figure 1 Effect of longitudinal prestrain on the retained ductility of notched longitudinal and transverse Armco iron tensile specimens.



(a)



(b)

Figure 2 Micrographs of sections normal to the fracture surface of notched longitudinal tensile specimens. Testing and prestraining direction is vertical. Fracture is nickel plated. a) Unprestrained; b) After 67 percent prestrain.

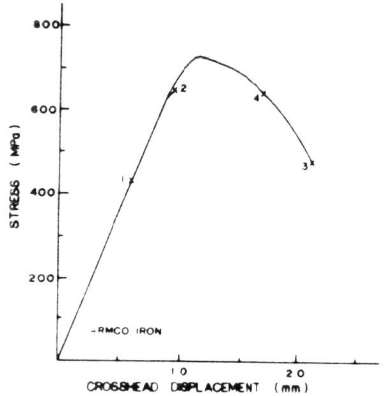


Figure 3 Effect of superimposed hydrostatic pressure during longitudinal prestraining on the stress vs. crosshead displacement of notched longitudinal tensile specimens. The specific superimposed pressures were 0, 310 MPa, 414 MPa, and 350 MPa respectively for specimens 1, 2, 3 and 4.

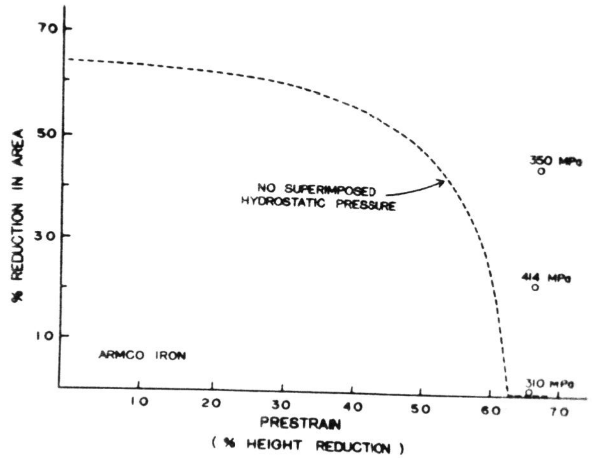


Figure 4 Effect of superimposed hydrostatic pressure during longitudinal prestraining on the retained ductility of notched longitudinal tensile specimens.