Fracture 1977, Volume 2, ICF4, Waterloo, Canada, June 19 - 24, 1977

IMPAIRED DUCTILITY IN SHEARED EDGES OF HSLA PLATES

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INTRODUCTION

Controlled-rolled, high-strength low-alloy (HSLA) steel sheets and plates are finding increasing application in the construction of vehicles and other equipment. Their higher strength (typically up to 80,000 psi or 560 MPa yield strength) is desirable for lighter-weight structures, but they suffer from a limited ductility, particularly in the transverse directions. Ductility is further reduced in sheared edges; this is particularly undesirable because most applications involve sheet metalworking techniques, typically shearing followed by bending, flanging and variants of drawing operations of varying severity. Low ductility and its directionality is attributable mostly to MnS inclusions of Types II and III, which deform during hot rolling and form families of stringers [1]. Ductility is improved by lowering the sulphur (and thus sulphide) content or, more practically, by the addition of elements that form higher-strength, globular, non-deforming sulphides.

MEASUREMENT OF DUCTILITY

One difficulty of research relating to HSLA steels has been the measurement of ductility as affected by sheared edges. In the preparation of the usual tensile specimens, the sheared edges are removed, and tests of a different geometry must be employed. The stretch-bend test, which was found to give results in agreement with press shop performance [2], clamps a narrow strip at its ends and then subjects it to a combination of bending and stretching by the penetration of the rounded, rectangular punch (Figure 1). The test is repeated with punches of different radii, and stretch-bend ductility is reported, for a standardized test geometry, as the depth of punch penetration (d) versus the bend ratio (r/t, where r is the punch radius and t is the sheet thickness).

With the sheared edge turned to the outer, tensile side during bending, there is a marked drop in transverse ductility in a steel that contains sulphide stringers while an only small drop can be ascertained in a Zr-treated steel (Figure 2) [3].

A knowledge of the quantitative effects of composition and processing variables on ductility in sheet metalworking operations is an obvious prerequisite for all further material development. A test that can provide a single ductility measure, similar to reduction in area in the tension test, should be of considerable value, providing that the effects of sheared or otherwise formed edges can also be assessed. This becomes possible in the secondary tension test [4], an outgrowth of the partial width indentation test [5]. It was originally developed for workability

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determination in bulk deformation processes, but its features make it suitable also for the present purpose.

THE SECONDARY TENSION TEST

The test is, in principle and in practice, very easily performed: a rectangular test piece, into which two holes had been drilled, is indented with two opposing anvils (Figure 3). The material displaced (extruded) between the anvils extends the test piece, subjecting the ribs located outside the drilled holes to tension. These tensile stresses are, in common with many metalworking processes, secondary tensile stresses, that is, they are induced by the deforming process itself. The ductility of the material is expressed as the reduction of area in the thinnest rib cross section after fracture. In common with other test methods, the ductility thus measured is somewhat sensitive to the test geometry; however, if the test geometry is standardized as shown in Figure 3, the results become highly reproducible and represent a true material property. The edge of the specimen may be sheared, ground, as-cast, or in any other technological condition, thus the effect of surface qualities on ductility may be quantitatively measured.

APPLICATION OF THE SECONDARY TENSION TESTS

To investigate the value of the secondary tension test for purposes of sheet metalworking operations, HSLA steel plates of 4.77 mm thickness were obtained (by courtesy of Stelco) in both the untreated and Zr-treated conditions. Metallographic examination showed both steels to have a fine (typically 20 μm) grain size, with numerous stringers in the untreated steel, and roughly equiaxed inclusions in the treated steel. For a complete characterization of mechanical properties, specimens cut from the two plates were tested in the longitudinal and transverse directions on standard two-inch gage length specimens. As shown in Table 1, properties were fairly uniform and ductility was roughly equal in the longitudinal and transverse directions when specimens with machined edges were tested.

The effect of sheared edges on ductility was investigated by testing secondary tension specimens which had one of the edges ground, the other in the as-sheared condition. The standard specimen geometry was obtained by the use of anvils 4 x 10 mm cross section, and the drilled holes were of 2 mm diameter. Accurate measurement of the rib dimensions prior to testing was possible with the use of a profilometer and a calibrated eye piece in a microscope, and the fracture area was determined by cutting out the fractured rib sections, photographing them and tracing the area with a planimeter.

For a correlation with the secondary tension test method, specimens were also prepared to give plane strain conditions. The cross section of the reduced section was 2 x 10 mm, and the data are included in Table 1. A comparison with the uniaxial tension test results shows a somewhat lower ductility because triaxial tensile stresses are induced in the plane-strain test from the very beginning and these lead to a reduced ductility. Compared to the plane strain tension test, the secondary tension test gives a yet lower ductility because of the stress-intensifying effect of the hole radius.

Of special interest is the marked drop in ductility in ribs prepared by shearing. The sheet material was not identical to that reported on in Figure 2, but was of the same class. The decrease in ductility was of the same general order, although a quantitative comparison is not possible because of the complex stress state existing in the stretch-bend test. It will also be noted that a reduced ductility was now measured in the sheared edges of the treated steel, and this unexpected result could be clarified only with a more detailed investigation of the particular sheet samples, including correlation with actual forming operations.

It should be noted that results quantitatively identical to plane strain tension can be obtained in secondary tensile tests if slots rather than holes are machined in the test piece.

TYPE OF FRACTURE

The photographs of fractured rib areas shown in Figures 4 and 5 reveal a marked difference in the fracture characteristics of the untreated and Zr-treated steels. Tested in the longitudinal direction, both treated and untreated steels exhibit a typically ductile, fibrous fracture. A centre split, observed also in the usual uniaxial tension tests [6], was however evident in the untreated steel. The fracture of transverse specimens was more irregular, and the greatest change in fracture pattern was observed in the ribs with as-sheared edges. Whereas fracture occurred in the minimum cross section in all ribs with ground edges, fracture followed a roughly 45° path from the minimum cross section in the as-sheared edges, and there were also numerous additional cracks in the strained zone of the latter. The fracture surfaces became highly uneven, and followed weak zones within the material.

CONCLUSIONS

Surface defects, cracks, introduced by prior processing steps can greatly impair the ductility of materials in subsequent forming operations that impose tensile stresses on the defective surface. The impairment of surface ductility can now be easily measured by the secondary tension test technique, and the loss of ductility can be quantitatively expressed through a single number. The usefulness of the technique has been demonstrated on HSLA plate; ductility in sheared edges was reduced to about one half the value found in ground edges of untreated steel and a similar effect was found in Zr-treated steel. The technique offers the opportunity of developing compositions and processing technologies on the basis of quantitative ductility indicators.

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Table 1 Mechanical Properties of Steels

Material	Test Direction	Uniaxial Tension						Plane Strain Tension		Secondary Tension	
		UTS MPa	K MPa	n	r (at 10%)	elong. (2 in.) %	R.A. %	UTS MPa	R.A. %	ground R.A. %	sheared R.A. %
Zr-Treated	L	662	930	0.11	0.70	24.5	61			53	30
		666			0.80	23.0	65			53	29
		663				22.7	63	724	60		
	T	680	990	.12	.96	24.7	57			44	17
		678			1.0	22.7	56			42	13
		678				25.0	61	742	52	45	15
Untreated	L	658	1,080	.135	.65	24.0	59			47	29
		652			.56	24.7	52			48	31
		657				22.5	60	718	58	41	27
	T	653	920	.11	.86	17.5	37			29	17
		652			1.06	14.3	36			30	15
		653				14.4	(26)*	675	(16)*	(17)*	14

* Specimen Delaminated

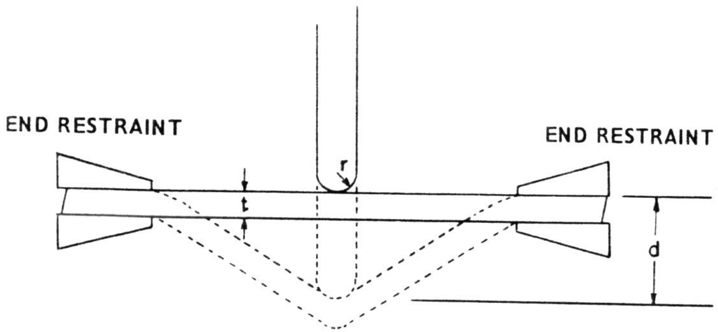

Figure 1 Geometry of the Stretch-Bend Test [2]

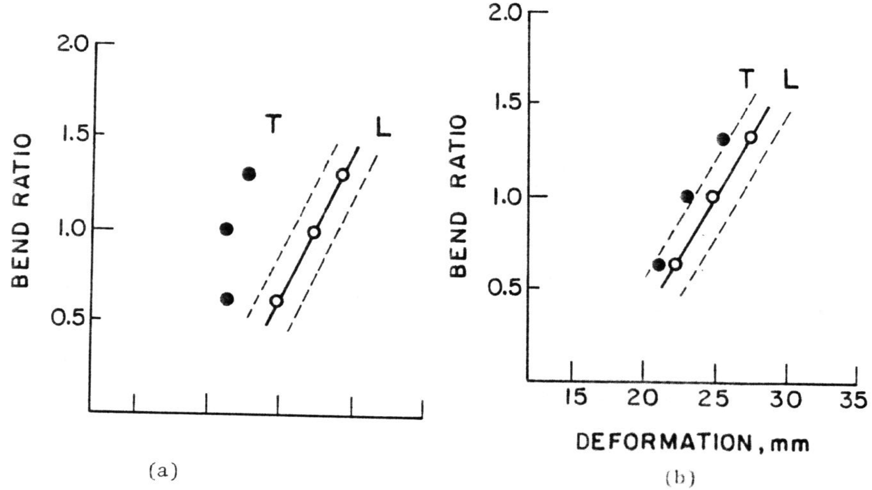

Figure 2 Stretch-Bend Ductility of HSLA Sheet
(a) Untreated; and (b) Zr - Treated [3]

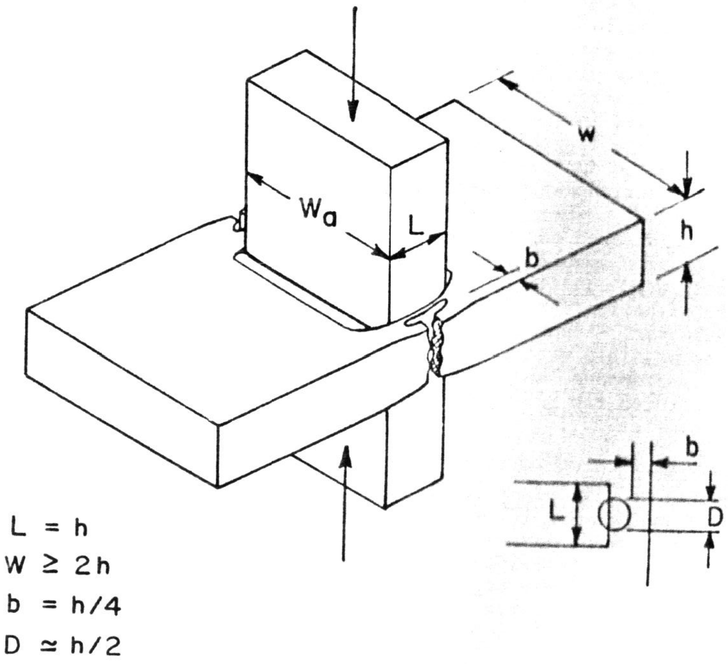

Figure 3 Geometry of the Secondary Tension Test

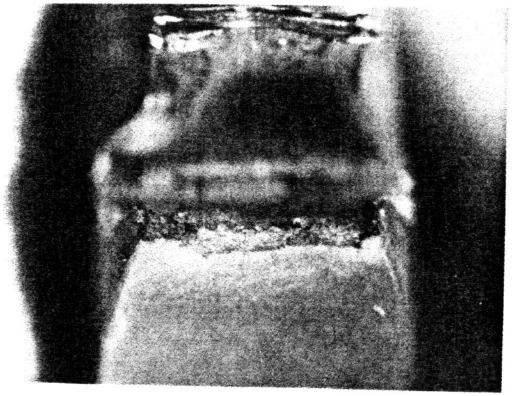

Figure 4 Fracture Surface with Ground Edge, Untreated Steel, Longitudinal Specimen

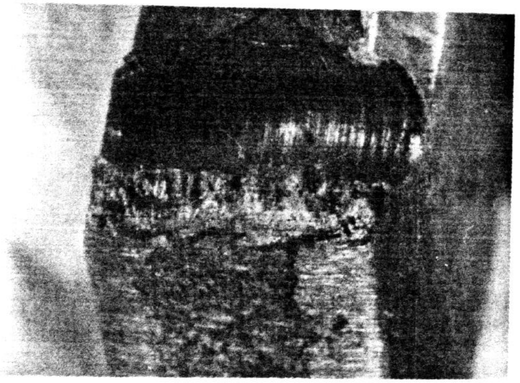

Figure 5 Fracture Surface with Sheared Edge, Untreated Steel, Transverse Specimen