RELATING BEND FORMABILITY AND FRACTURE TOUGHNESS

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ABSTRACT

Plane strain formability and fracture toughness were determined for copper and 70/30 alpha brass rolled to a range of cold reductions to vary strength and ductility. Bend formability was assessed by the minimum radius which would successfully make a 90° bend without evidence of cracking. The Khan tear test was used to assess unit propagation energy as a measure of fracture toughness. The results showed that anisotropic bend ductility develops with increasing cold reduction and is reflected in anisotropic fracture toughness. This anisotropy is not related to grain shape, but may be related to crystallographic and substructure changes.

KEYWORDS

Bend formability; fracture toughness; anisotropy; copper alloys.

INTRODUCTION

Copper alloy strip characteristically shows anisotropic bend ductility, the magnitude of which depends upon alloy content and cold rolling reduction. The cause of this anisotropy has been linked to the development of crystallographic texture rather than mechanical fibering [1]. There has, however, been little quantitative work relating the strain to fracture in bending to mechanical properties [2,3]. To this end, bend ductility and fracture toughness measurements of ETP-Copper (C110) and alpha-brass (C260) were compared. It was specifically of interest to determine whether the anisotropy in bend ductility would be reflected in the fracture toughness results.

EXPERIMENTAL MATERIALS AND RESULTS

C110 (ETP-Copper) and C260 (70 Cu-30 Zn alpha brass) were obtained as commercially produced hot rolled plate. Subsequent laboratory processing was controlled to minimize annealed texture prior to final cold reduction and to provide a constant thickness after final rolling, as detailed in Table 1. Finish rolling reduction varied between 10 and 60% for C260 and between 40 and 80% for C110.

Ultimate tensile (UTS) and 0.2% offset yield (YS) strengths were determined as a function of final cold reduction. Minimum bend radius (MBR), defined as the smallest radius at which no cracking is visible at 10 times magnification was determined for a 90° bend. The minimum bend radius is reported in multiples of sheet thickness. The bend test procedures used are similar to those of Arrangement B of ASTM Standard Method E290 [4]. The Khan tear test was used to determine unit propagation energy (UPE) as a measure of fracture toughness [5]. All properties were determined in the longitudinal and transverse directions.

Tensile, bend and fracture toughness test results are given in Table 2. Minimum bend radius is plotted against 0.2% offset yield strength in Fig. 1. C260 shows marked anisotropy at strength levels corresponding to rolling reductions above 30%. C110 shows anisotropy above 60% rolling reduction, although the degree of anisotropy is less than that seen for C260. Figure 2 plots unit propagation energy against 0.2% offset yield strength and shows an anisotropy in fracture toughness corresponding to that seen in bend ductility. Bend ductility and fracture toughness are examined further in Fig. 3. Unit propagation energy is divided by yield strength in order to normalize data for both alloys. Minimum bend radius is expressed in terms of bending strain at the outer fiber, as $\frac{R}{t} = \frac{1}{(1+\varepsilon)2 - 1}$. The sharp change in the linear bend ductility-toughness relationship at about 10^{-2} UPE/YS corresponds to the onset of anisotropic behavior.

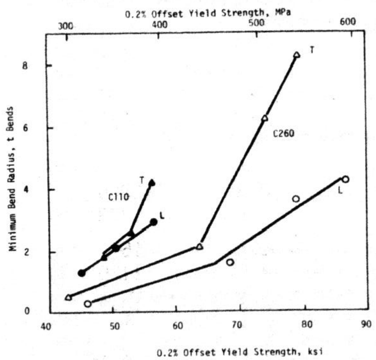

Fig. 1. Minimum bend radius versus yield strength.
L = longitudinal;
T = transverse.

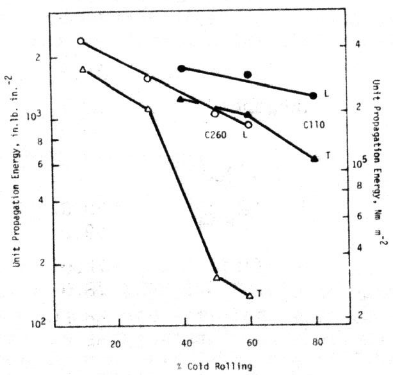

Fig. 2. Semi-logarithmic plot of unit propagation energy versus % cold rolling reduction for C110 and C260. L=longitudinal; T=transverse.

TABLE 1 Processing History

C110

Hot Rolled Plate at 0.3" + CR (1) + 600°C/1 hr. + 50% CR + 350°C/1 hr. + Final Cold Roll to 0.030" Gage.

C260

Hot Rolled Plate at 0.4" + CR (1) + 490°C/1 hr. + CR 30% + 415°C/1 hr. + Final Cold Roll to 0.030" Gage.

Note: Final cold reductions of 40 to 80% were used for C110 and 10 to 60% were used for C260. CR (1) was adjusted to provide a constant finish gage of 0.030".

TABLE 2 Mechanical Properties

Condition		UTS	YS	MBR	UPE
Alloy 110					
40% CR	L	49.0	45.0	1.3	1700
	T	49.5	48.5	1.8	1231
60% CR	L	54.5	50.5	2.1	1570
	T	56.5	52.9	2.6	1006
80% CR	L	60.5	56.5	2.9	1287
	T	60.5	56.5	4.2	615
Alloy 260					
10% CR	L	58.0	46.0	0.3	2826
	T	59.0	43.0	0.5	1773
30% CR	L	72.0	68.5	1.6	1571
	T	78.0	63.8	2.1	1120
50% CR	L	90.5	78.8	3.6	1040
	T	95.5	74.3	6.2	171
60% CR	L	94.0	86.5	4.2	901
	T	101.5	79.5	8.3	140

* UTS and YS in ksi, multiply by 6.89 to give MPa
UPE in in.-lbs./in.^{2}, multiply by 175 to give Nm m^{-2}
MBR in multiples of sheet thickness

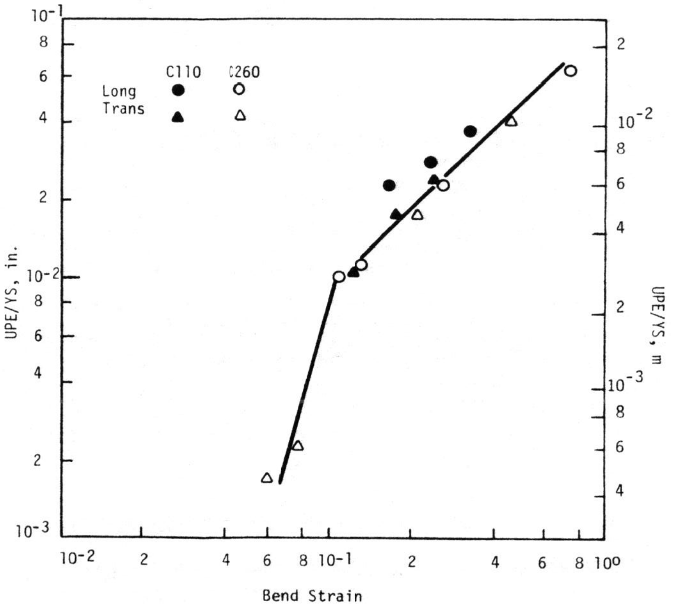

Fig. 3. Unit propagation energy (UPE) normalized by yield strength (YS) versus bend strain at fracture. Logarithmic scale.

DISCUSSION

The rolling reduction required to develop anisotropy and its relative intensity are consistent with stacking fault energy and crystallographic texture effects expected from previous work [1]. In addition, the bend ductility results also show a good correlation with unit propagation energy. The fit with toughness is not related to grain shape effects inasmuch as there is no direct scaling with percent rolling reduction. The work expended in crack propagation would depend on strain hardening and strain distributing capacity. This suggests that toughness is revealing underlying changes in texture and substructure.

The substructures of C110 and C260 as a function of cold rolling reduction are becoming more completely documented [6,7]. However, significant additional deformation occurs during bending and it cannot be assumed that the cold rolled substructure actually represents the structure through which bend fracture propagates. Consequently, structure studies as a function of bending deformation would be useful.

CONCLUSION

Anisotropy in bend ductility evidenced as reduced transverse properties correlates with a sharp reduction in transverse fracture toughness. This is

not uniquely related to grain shape effects, but may be explained by substructure and texture factors.

ACKNOWLEDGMENTS

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