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An assessment of a copper-containing
drawing-quality steel sheet

- by -

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An assessment of Jouvencel, a copper-containing,
drawing-quality, sheet-steel, ex S.A. Metallurgique
Esperance-Longdoz.

This material has been produced in an attempt to provide a sheet steel of enhanced drawability. The claims made for this material are that it has a high r-value with a low Δr -value and a good ductility, as measured by the n value, or uniform elongation, though ductility is slightly decreased by the presence of copper.

We have examined a sheet of this steel provided by the Copper Development Association and our results and conclusions are given below.

1. Composition

This analysis was carried out by the Steel Company of Wales Ltd.

C	S	P	Mn	Ni	Cu	Sn	Al(total)	N
0.020	0.019	0.013	0.31	0.035	0.090	0.01	<0.01	0.0006

It will be noted that the copper is only about one-third of that specified in the literature on this steel.

2. Tensile-test properties

	0°	45°	90°
Yield strength (Y)	21,100 18,900	22,400 22,400	21,300 20,900
Tensile strength (T)	40,300 36,100	42,200 22,000	41,900 41,600
Uniform elongation (eu)	0.30 0.30	0.28 0.28	0.30 0.30
Strain hardening exponent calc. from above) (n)	0.26 0.26	0.25 0.25	0.26 0.26
Strain ratio (r)	1.36 1.37	1.49 1.49	2.16 2.16

These figures agree well with those already published. A point noted was the tendency of certain specimens to curl round the axis of applied tension during the test.

3. Biaxial Tests

A number of biaxial tests were carried out to measure the maximum strain in biaxial tension, the Erichsen value and the earing behaviour.

A stress (σ) strain (ϵ) curve in biaxial tension was also produced to allow comparison with uniaxial behaviour (see sect. 4). Certain of the 4.5" dia. bulges fractured uncharacteristically away from the pole (Figs. 1 and 2).

3.1 Stretch forming

3.1.1 hydraulic

1 - in. dia. bulge. Maximum surface strain (a) 0.53 (b) 0.54
cup depth 0.463 in.

2 - in. dia. bulge. Maximum surface strain 0.52
cup depth 0.947 in.

4.5 - in. dia. bulge. Maximum surface strain 0.50
cup depth 1.75 in.

3.1.2 punch stretching

Erichsen test (a) 11.9
(b) 11.8 ($\approx .469$ in.)

Two - in. dia. punch-stretching test. Maximum surface strain 0.55
cup depth 0.936 in.

3.2 Drawing

A drawn cup is shown in Figure 3. It will be seen that the ears form at 0° at 90° to the rolling direction, with troughs at 45° . The ears are less severe than in aluminium-stabilised or a rim-steel.

No attempt was made to determine the l.d.r. of this material as this value is strongly affected by friction and tool design, and as yet no standard procedure has been laid down for this test.

4. Uniaxial and biaxial stress/strain relationships.

Figure 4 shows the σ / ϵ curves of this material. The expected texture strengthening is observed for an anisotropic material of this type in biaxial tension. The calculated values for $\sigma_{x/x}$ (at a strain of 0.01) is 1.27 compared with the theoretical value of 1.15, calculated from the relationship

$$\sigma_{x/x} = \frac{r + 1}{2}$$

5. Microstructure

The etched and unetched microstructures ($\times 400$) are shown in Figures 5 and 6. A variation in grain size from edge to centre can be observed, and also the presence of inclusions which tend to lie near the surface of the steel.

Conclusions

The composition is unusual in that the copper content is much lower than would have been expected. As the \bar{r} -values are very similar to those quoted in the literature it would seem that the critical copper-content to produce the appropriate texture is lower than that previously stated. The mechanical properties are those of a best-quality edd steel with low yield strengths low Y/U ratios and high uniform elongations. \bar{n} values were quoted as these are currently in fashion, but were calculated from the relationship: $\epsilon = \ln(1 + e)$. This procedure is valid as this material obeys the relationship $\sigma = k\epsilon^n$. The curling of the tensile test pieces is interesting. This implies a variation in texture in the through thickness direction; this suggestion is strengthened by the grain-size variation - it is possible also that there is a compositional variation through the thickness which could account for the recrystallization behaviour. This was not investigated. The uniaxial and biaxial σ/ϵ curves were determined and σ_x/x computed to highlight another manifestation of normal anisotropy, namely a variation in yield and flow behaviour under different loading conditions.

The fractures of the large bulges away the pole may be ascribed to the non-metallic inclusions in the steel or possibly to the rolled-in oxide particles visible on the surface. Either of these could act as stress concentrators causing instability away from the pole leading to premature failure.

FIG. 1 4½" DIAMETER
BULGE FRACTURE
AWAY FROM THE
POLE OUTSIDE VIEW

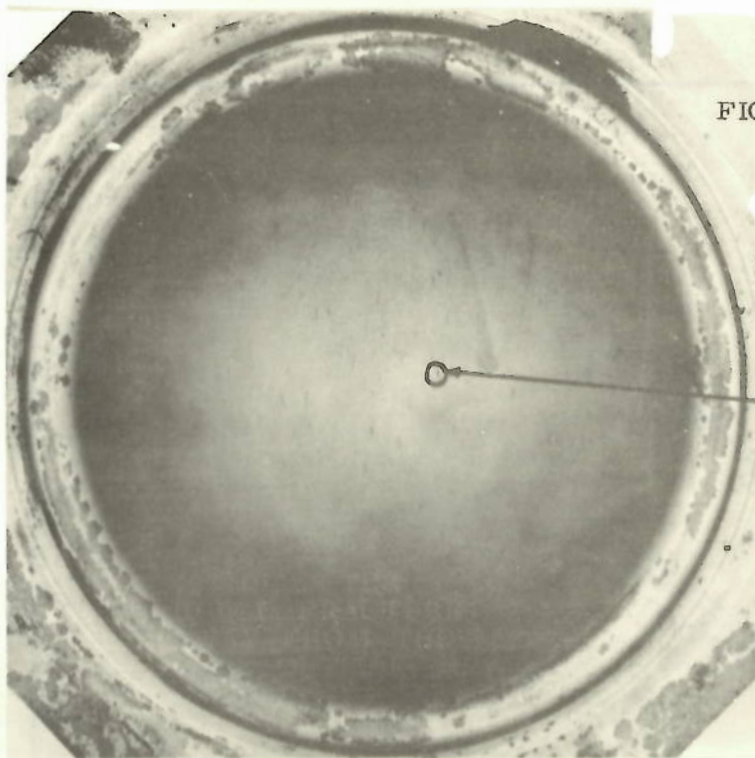
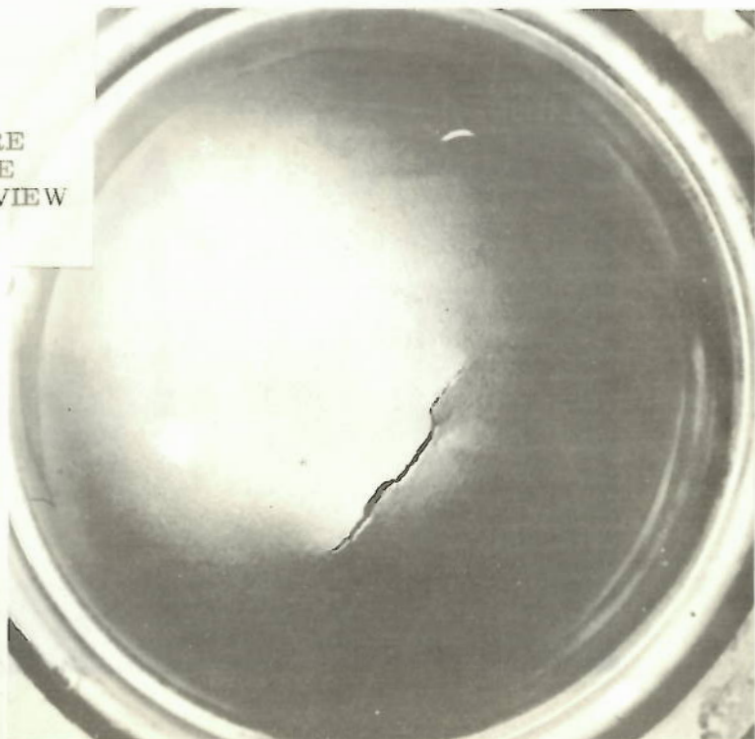


FIG. 2 4½" DIAMETER
BULGE INSIDE
VIEW. FRACTURE
FROM SURFACE
IMPERFECTION

fracture

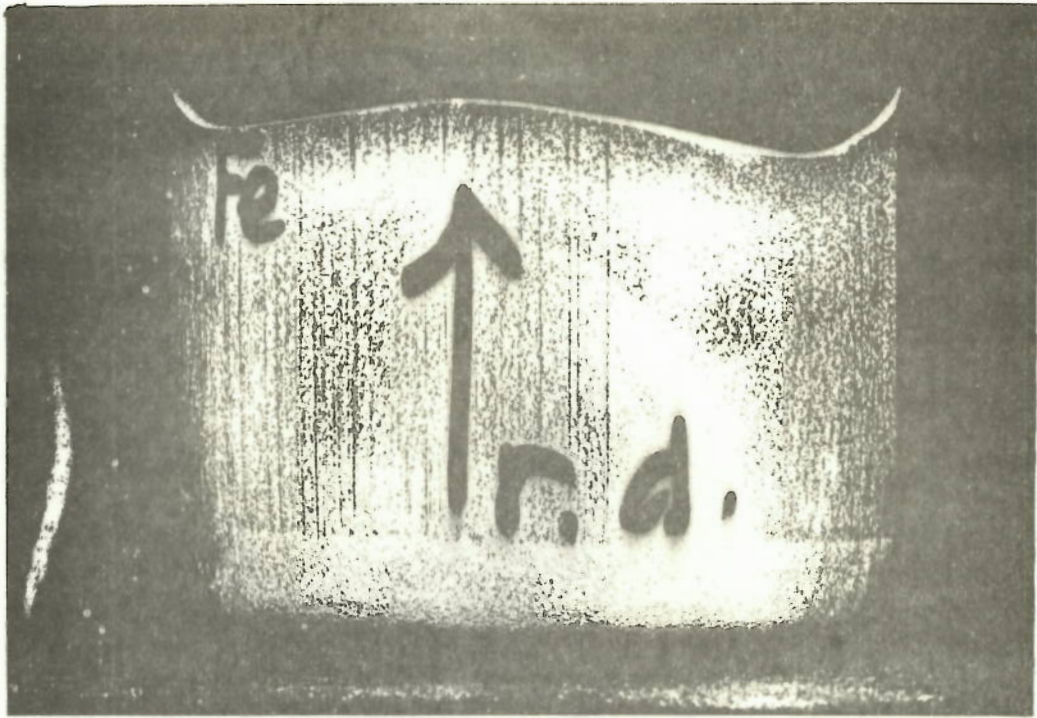


FIG. 3 2" DIAMETER DRAWN CUP, SHOWING EARS IN THE ROLLING DIRECTION; TROUGHS AT 45°.

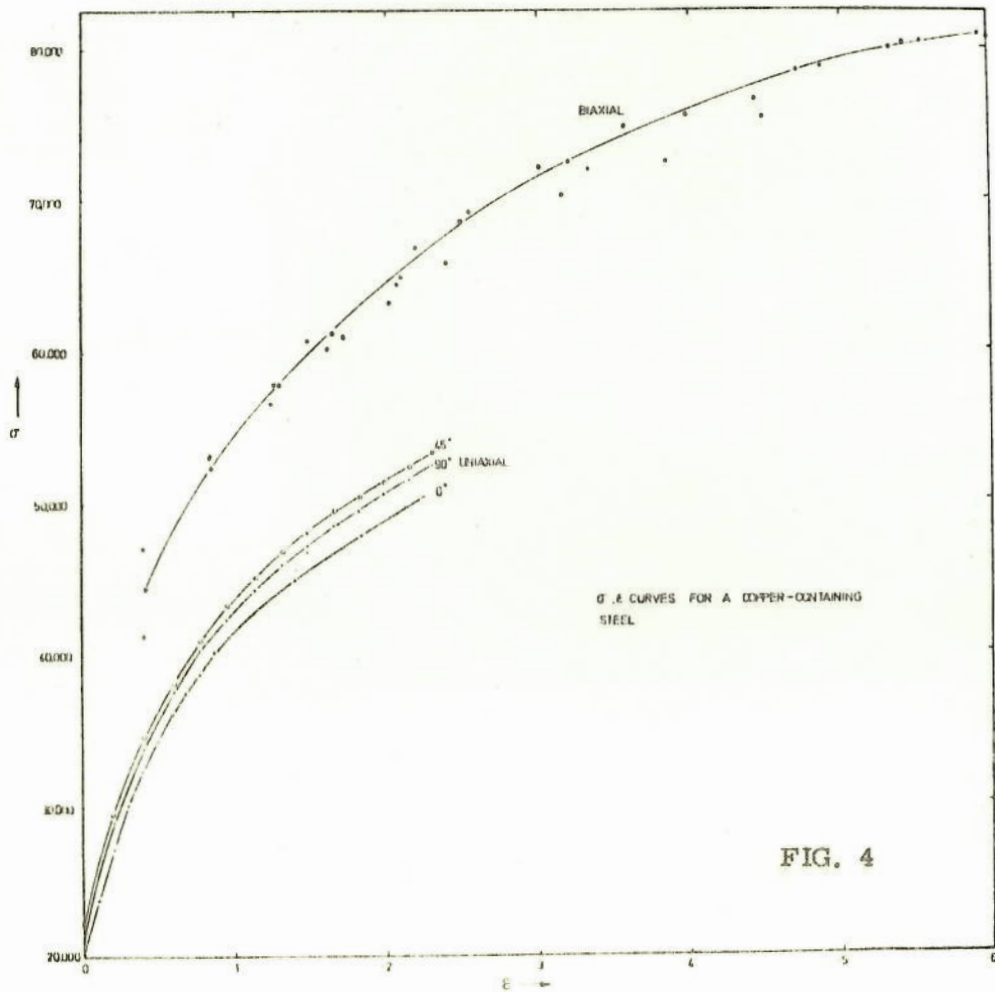


FIG. 4



FIG. 5 UNETCHED X 400 SHOWING NON METALLIC INCLUSIONS



FIG. 6 ETCHED X 400 SHOWING EDGE → CENTRE GRAIN SIZE VARIATION