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Extended plasticity in commercial-purity zinc sheet

- by -

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SUMMARY

99.1% pure zinc, when rolled at room temperature to reductions in excess of 50%, shows properties grouped under the general title of 'extended plasticity'. At these reductions, the flow stress and elongation show an increasing strain-rate sensitivity, and at 80% reduction, at which most of the tests reported here were done, the conventional large twinned grains were converted to a stable sub-grain structure 2-3 microns in diameter. This structure remains apparently unchanged after about 120% elongation in uniaxial tension; no evidence of slip or twinning has so far been observed under the electron microscope.

Work to elucidate the deformation mechanism is continuing.

Introduction

In the course of a different research, commercial purity zinc was rolled down to 0.036 in. sheet and this as-rolled material was found to behave exceptionally in biaxial stretch-forming operations (Fig. 1a) in sharp contrast to the same material after receiving a recrystallizing anneal (Fig. 1b). It was considered worthwhile to investigate this matter further and the results so far obtained are the subject of this report. It is considered that this metal exhibits properties akin to those of superplastic materials, but the extremely high elongations and m values are not achieved. Consequently, the term 'extended plasticity' has been coined to characterize these phenomena.

Material

The material used was commercial-purity zinc, supplied by R.T.Z. Ltd., in the form of plate 0.192 in. thick. A spectrographic analysis recorded the following:

Pb	Cd	Fe	Cu	Al	Ti	Mg	%
0.8	0.05	0.02	0.002	0.001	0.001	0.001	

Experimental

Uniaxial tensile tests were carried out using an Instron tensile testing machine, at speeds varying from 0.002 - 20.0 ins/min.

Biaxial tests were carried out on a Hille Engineering Ltd., press, capable of applying 8 tons blankholder load; an adequate load to suppress drawing in. A thiokol-rubber-block, positioned on a flat-topped punch was used to simulate hydraulic pressure.

Results

Figure 2 shows the effect of rolling upon uniform elongation (e_u) i.e. the elongation not associated with making and fracture; additionally, this parameter is unaffected by metal gauge. It will be seen that below 50% reduction, e_u is in the range 15-19%, while after 50% the uniform elongation rises to 70%, increasing to 130% at 90% reduction. All these tests were carried out at a machine crosshead speed of 0.2 in/min.

Figure 3 shows the total elongation plotted against rolling reduction for crosshead speeds of 0.2 and 20.0 in/min. At the slow speed, the increase in e_t with percentage reduction can be seen, even though the cross-section of the test piece is diminishing. This variable is responsible for masking the discontinuity observed in Figure 1. At the higher speed, the reduction of e_t with increasing crosshead speed is another example of the increasing strain-rate sensitivity with increasing rolling reduction, while

Figure 6 shows the effect of a range of strain rates on zinc reduced by 80%.

An effect of annealing is shown in Figure 5. Speed of testing has virtually no effect on the total elongation for material rolled and then recrystallized (5 mins. at 120°C). The shape of this curve is judged to be due to a grain-size effect, i.e., 60% reduction before recrystallization giving the grain size for optimum ductility. Figure 4 shows the function $(e_{t_{0.2}} - e_{t_{20.0}})$ [where $e_{t_{20}}$ is the total elongation at 20 in./min. crosshead speed, similarly for $e_{t_{0.2}}$], plotted against rolling reduction. The effects of strain-rate are again evident.

The stress-strain curve of a material which exhibits strain-rate dependence may be represented by the relationship:

$$\sigma = k\dot{\epsilon}^{m}$$

where σ is the true stress, $\dot{\epsilon}$ is the strain-rate and $\underline{m}$ is the strain-rate exponent. For most metals the value of $\underline{m}$ is less than 0.1 and in the case of recrystallized zinc, $m = 0.06$. For a superplastic material, $\underline{m}$ may be 0.5; $\underline{m} = 1$ for pure Newtonian flow. The 80% rolled zinc in this work gives $m = 0.20$.

During rolling, the large equiaxed, twinned grains, become increasingly fragmented and a very fine stable subgrain structure is produced of about 2-3 microns. A preliminary examination by electron microscopy indicates that the grain size and shape remain substantially unchanged after straining.

Conclusions

Heavily-rolled commercial-purity zinc is composed of subgrains 2-3 microns in diameter, and remains in this condition at room temperature. Marked differences are observed in the plastic behaviour of this as-rolled and the recrystallised metal:

(1) No evidence of slip lines in the as-rolled metal, while slip is observed after annealing.

(2) The e_u of the recrystallised is not strain-rate dependent; over the same range of strain rates e_u varies for the as-rolled metal from 5% - 110%.

(3) The recrystallized metal strain hardens during straining, the as-rolled metal does not.

(4) The tensile strength as-rolled is proportional to log $\dot{\epsilon}$; the tensile strength of the recrystallized metal is relatively insensitive to rate of strain.

Discussion

No detailed discussion of this work is yet possible, as only the phenomenology is established. It seems reasonable, however, to postulate that the fine subgrain size, coupled with processes such as grain boundary migration and sliding, and grain rotation, are responsible for this behaviour. Diffusion must also be invoked to maintain coherency between the subgrains.

Work is now concentrated on the microstructural aspects of this phenomenon.

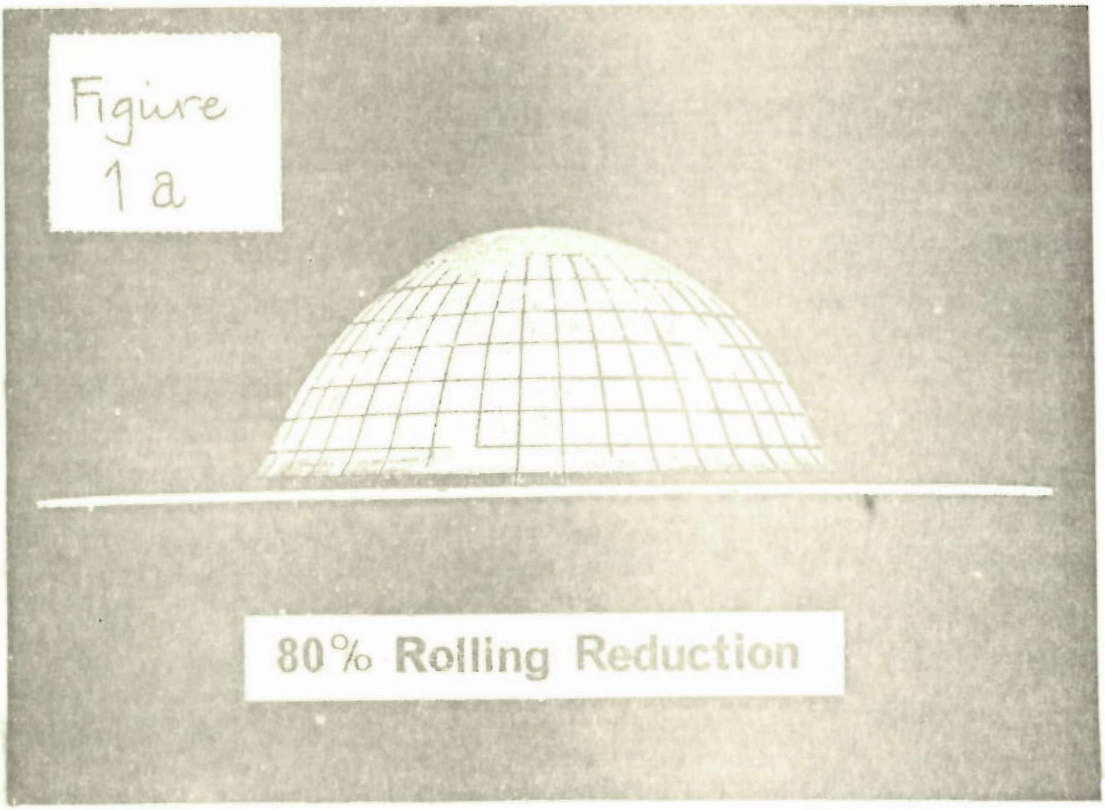


Figure 1a

80% Rolling Reduction

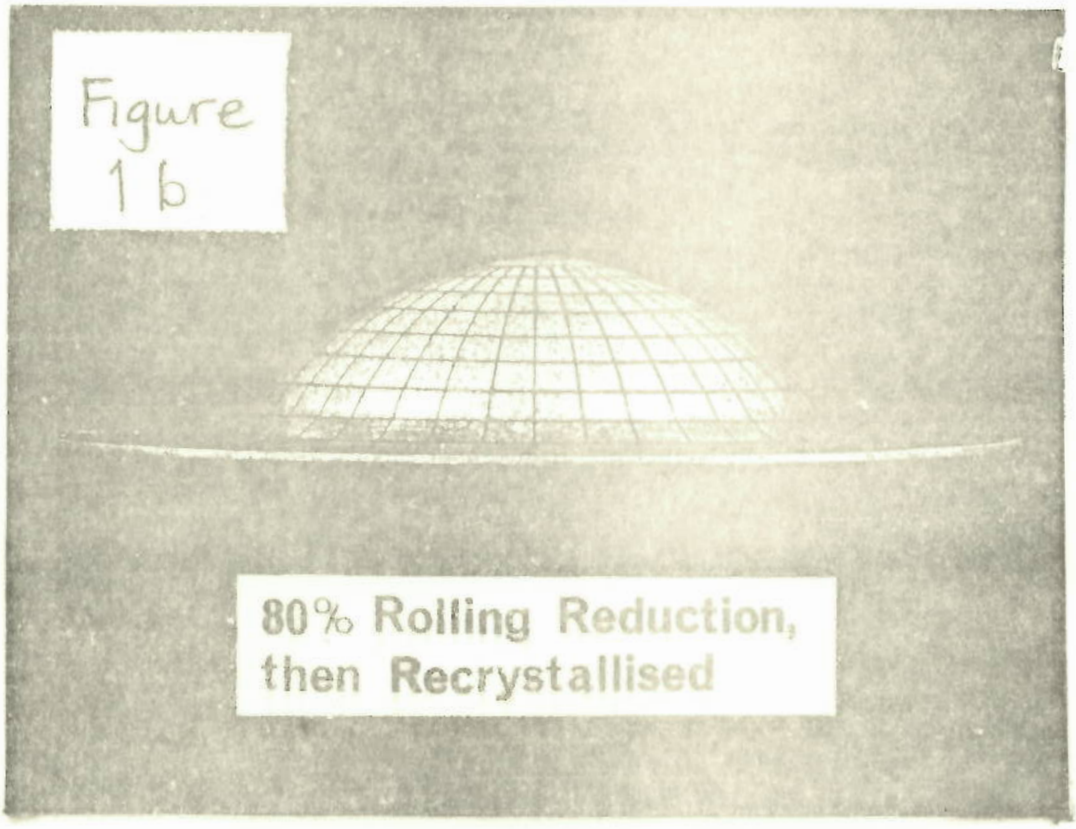


Figure 1b

80% Rolling Reduction, then Recrystallised

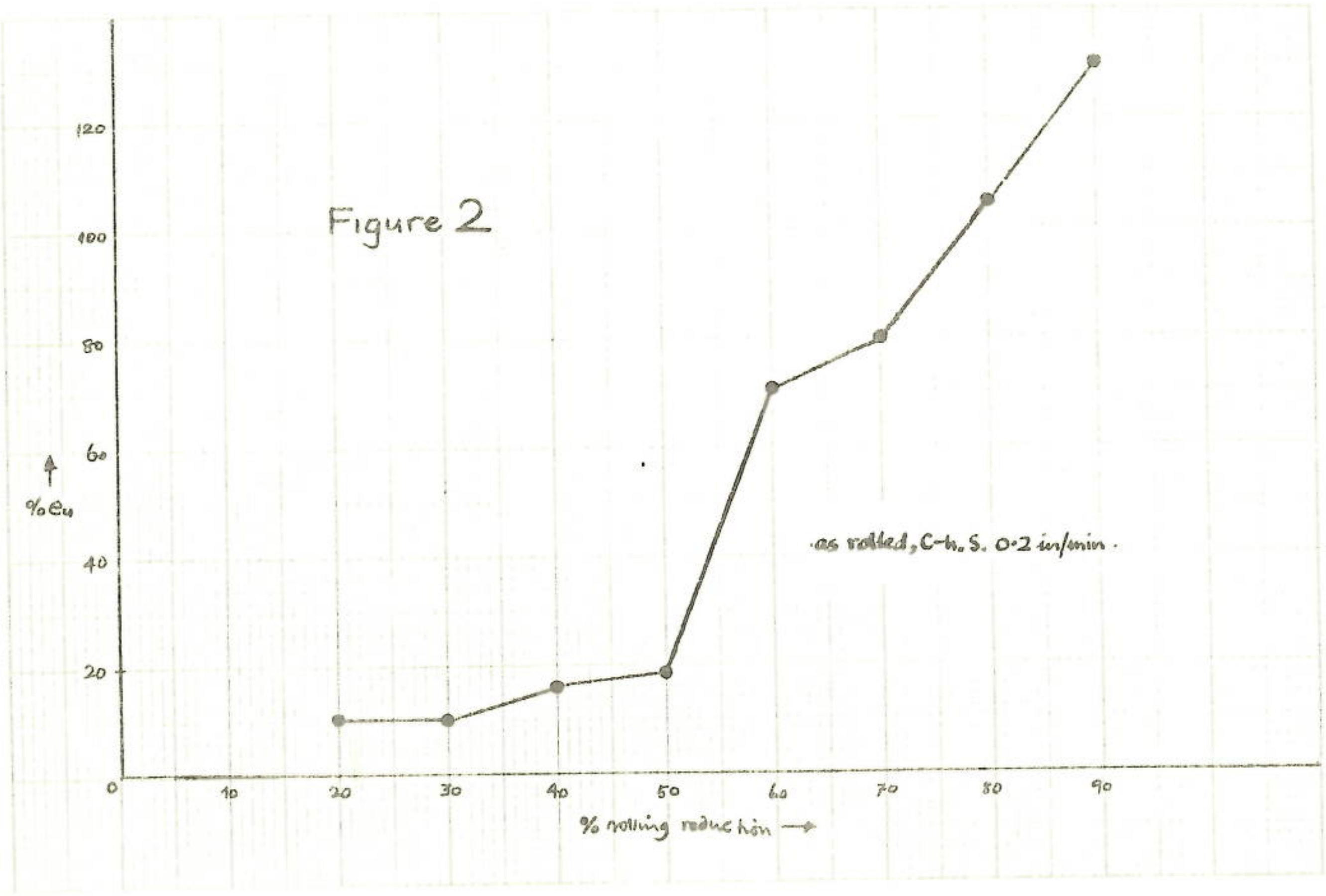


Figure 2

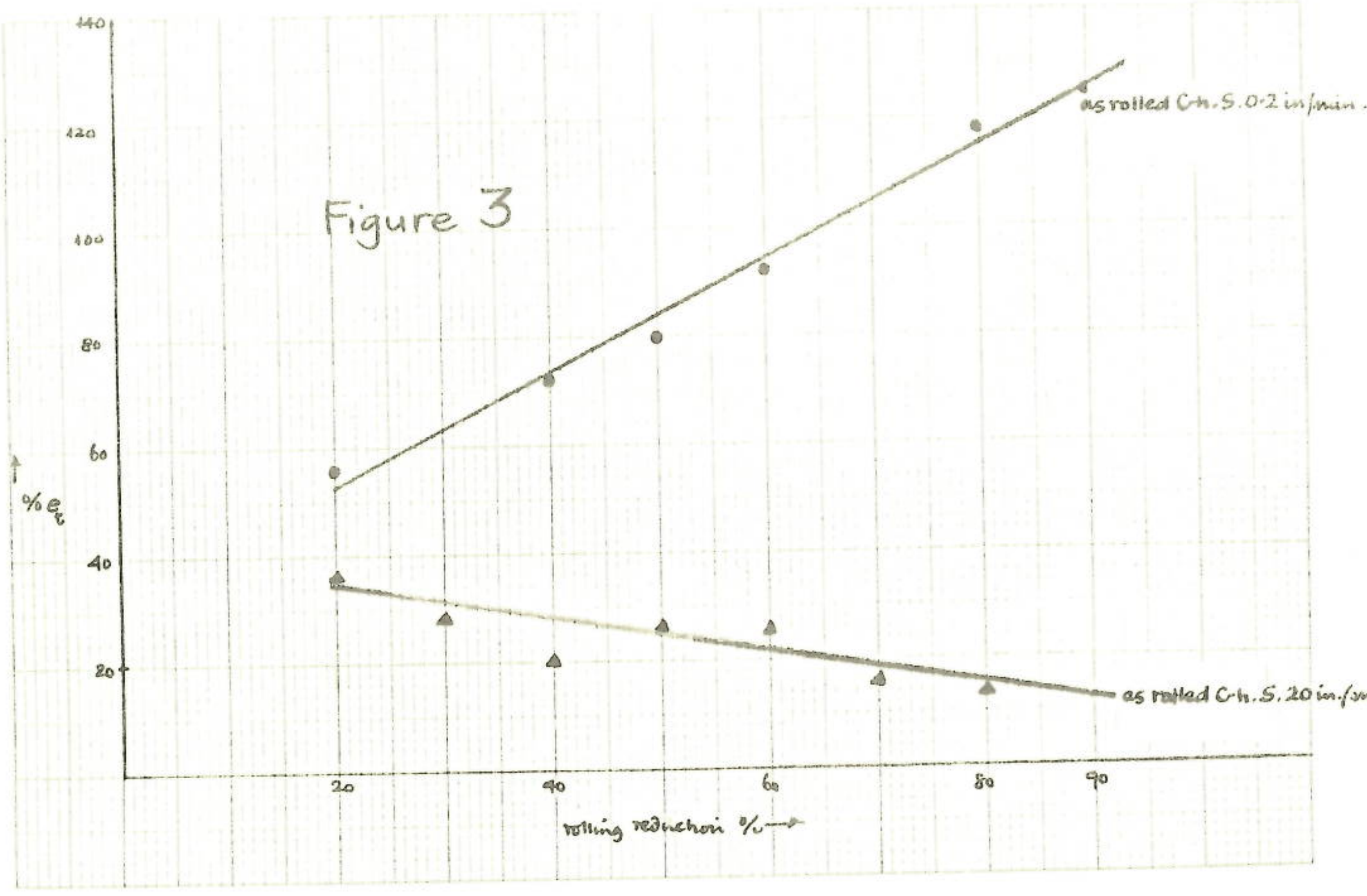


Figure 3

Figure 4

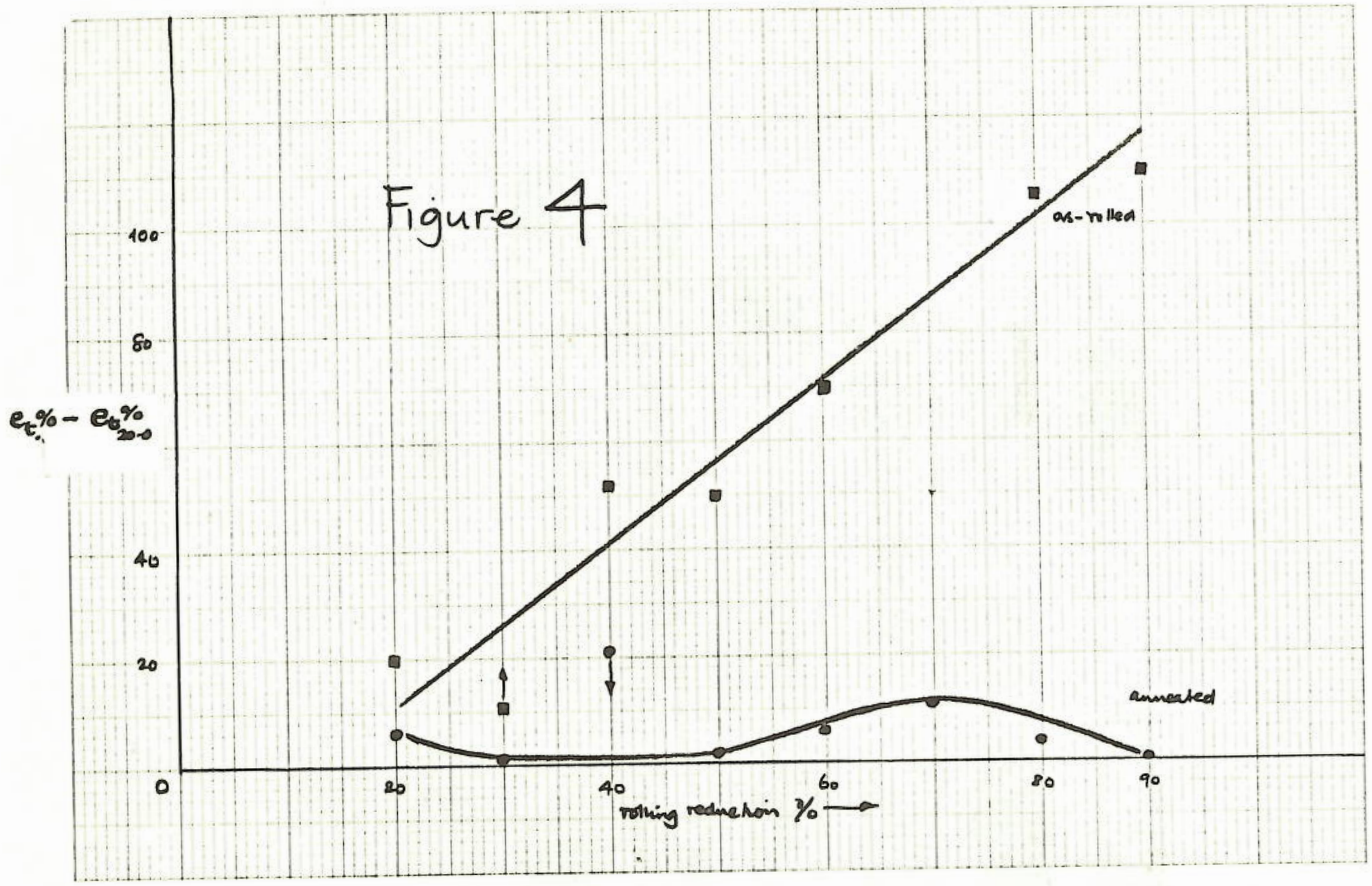
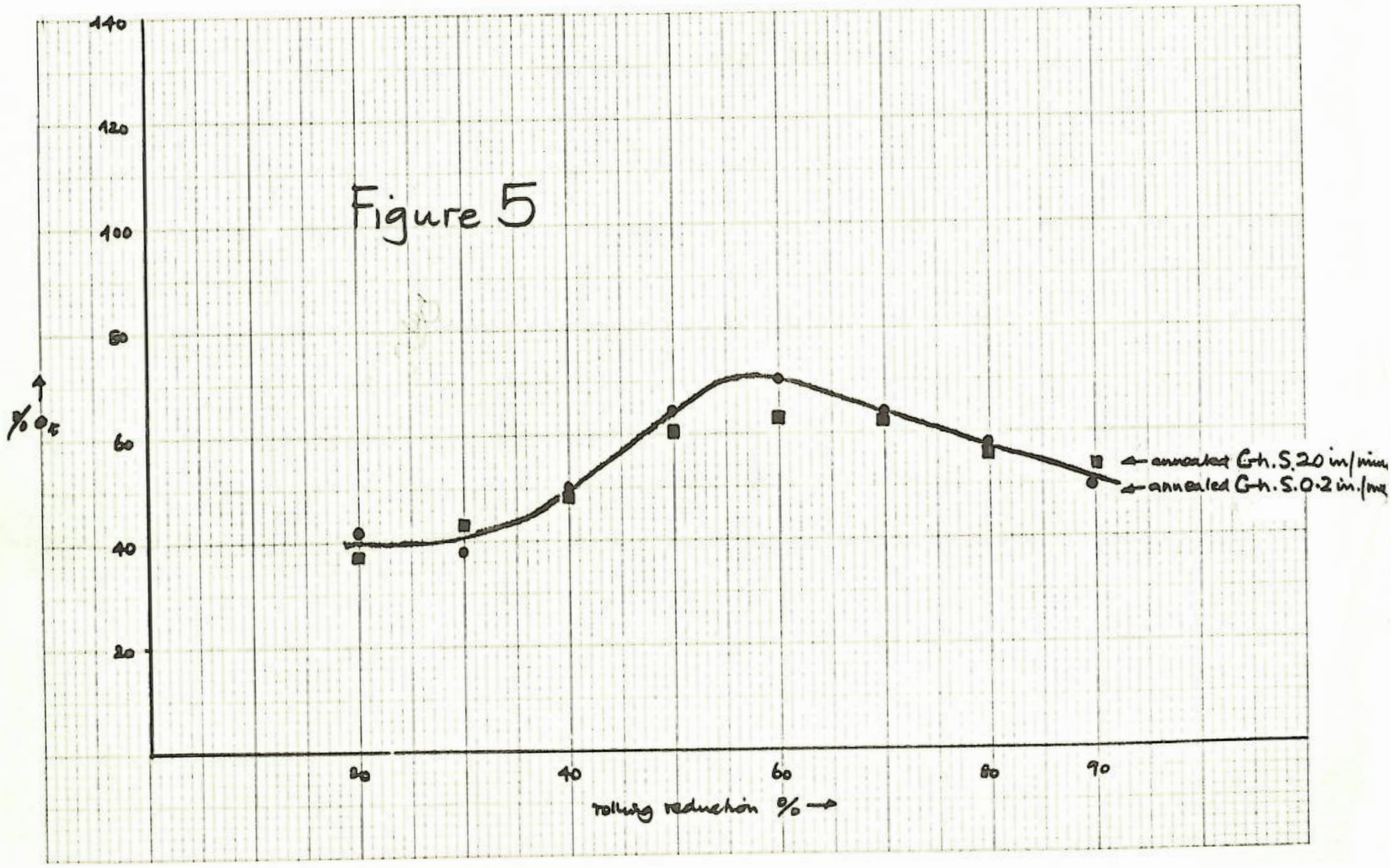


Figure 5



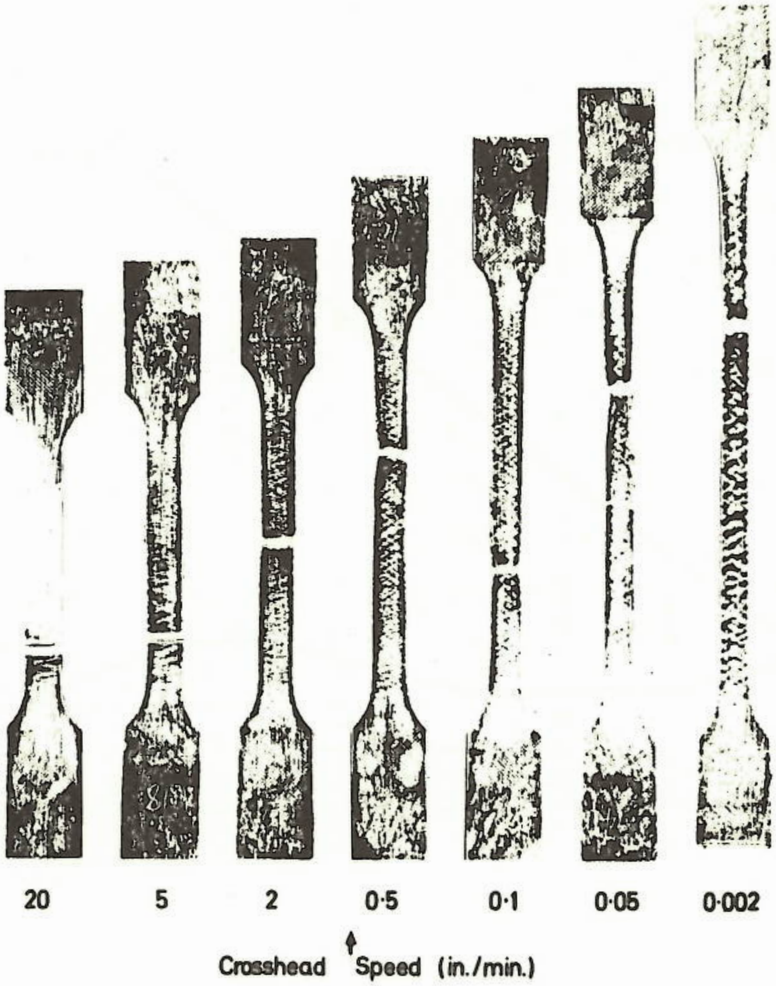


FIG. 6