THE RELEVANCE OF THE PARAMETER YIELD STRENGTH TO ULTIMATE TENSILE STRENGTH RATIO IN SHEET METAL FORMING OPERATIONS AND A NOTE ON THE IMPORTANCE OF ANISOTROPY IN ENGINEERING APPLICATIONS

In a sheet metal pressing operation the limit of formability is reached at the onset of instability which may manifest itself as buckling or necking. YS/US is important in both these situations.

Buckling

Wallace has shown that the tendency to buckling increases with increasing yield strength and decreases with increasing modulus. To a first approximation the modulus is a fixed property, but on closer study it is found that the modulus varies with variation in crystallographic texture and that a higher modulus results from increasing the (111) component in the sheet plane. Stabilised steels have a greater proportion of (111) planes in the plane of the sheet than rimming steels and the resistance to buckling of these steels, due to the higher resulting modulus, has been demonstrated under press-shop conditions. (Fig.1.) Turning now to the YS/US ratio work by Pearce has shown (Fig.2, 3, & 4) the effect of increasing YS/US on buckling in a particular motor-car pressing. It is clear from this that ageing, which effects the ultimate strength, adversely affects the production of pressings prone to buckling.

At present work is being carried out in Japan on "shape fixability", an umbrella-term covering buckling and spring-back. The Japanese have confirmed Wallace's findings, agreeing that spring-back is controlled firstly by modulus, and secondly by slope of the stress-strain curve, a measure of the work hardening behaviour of the material.

Most ductile metals of the type used in high-production sheet-metal forming operations, i.e. fcc and bcc metals deforming on multi-slip systems, can be represented more or less approximately by a curve of the form $\sigma = K\varepsilon^n$. It can be shown that at instability $\varepsilon = n$. YS/US can also be expressed in terms of σ and ε and the expression YS/US = $\left[\frac{k}{n}\right]^n$ can be derived. Thus there is a quantitative relationship between YS/US and work-hardening behaviour for $\sigma = k\varepsilon^n$ type materials, and it is suggested that there may well be a qualitative relationship between YS/US and n for other metals which do not conform to this empirical equation.

To sum up then, under this heading, a low value of YS/US is important for elimination of buckling and spring-back type failures in metal pressings.

Necking

To prevent necking in a stretch- rather than a draw-controlled pressing it is essential, amongst other things, to have a material of maximum ductility usually exemplified by a high value of the work-hardening exponent n or the natural strain at maximum load ε_u, or the uniform elongation e_u, or the YS/US ratio. Relationships between these various parameters for a $\sigma = k\varepsilon^{n}$ type material are shown in Figs. 5, 6, and 7.

Summarising then, a low value of YS/US is essential for the production of pressings.

In addition, there is another very important point to be brought to the attention of design engineers. The strain-ratio r, a measure of a material's resistance to thinning, may also be interpreted as a different value of the strength in the through-thickness (z) direction, from that in the sheet plane. For values of r greater than unity a strengthening in the z direction is obtained and Figure 8 shows the relationship which applies.

The von Mises yield-criterion, which represents the yielding of material under combined stresses becomes an ellipse for the special case of loading in the sheet plane. The distortion of the ellipse from the isotropic case (r = 1) is shown in Figure 9. The advantages which could result from using a high r value material are clear and the question of the numerical value of yield stress to be used in a design calculation is highlighted.

Cranfield, March 1966. R.PEARCE

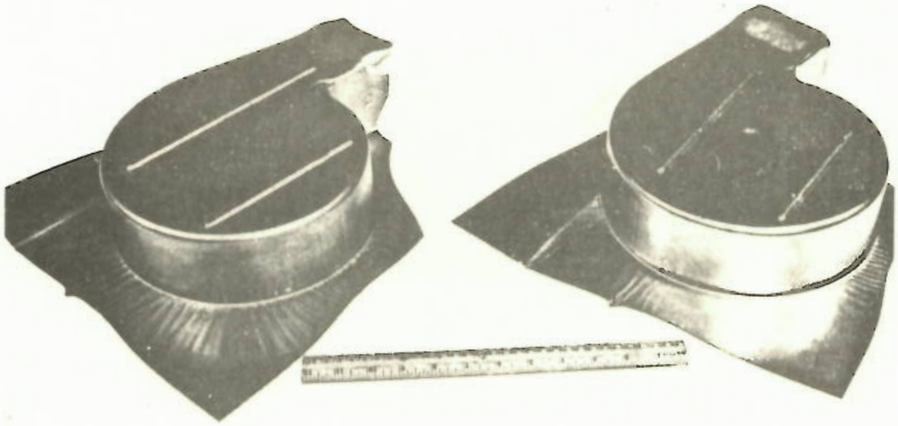

FIG. 1 INCREASED WRINKLING OF FLANGE IS EVIDENT ON LOW (0.98) r VALUE HOUSING ON LEFT. HOUSING ON RIGHT FROM HIGH (1.52) r VALUE.

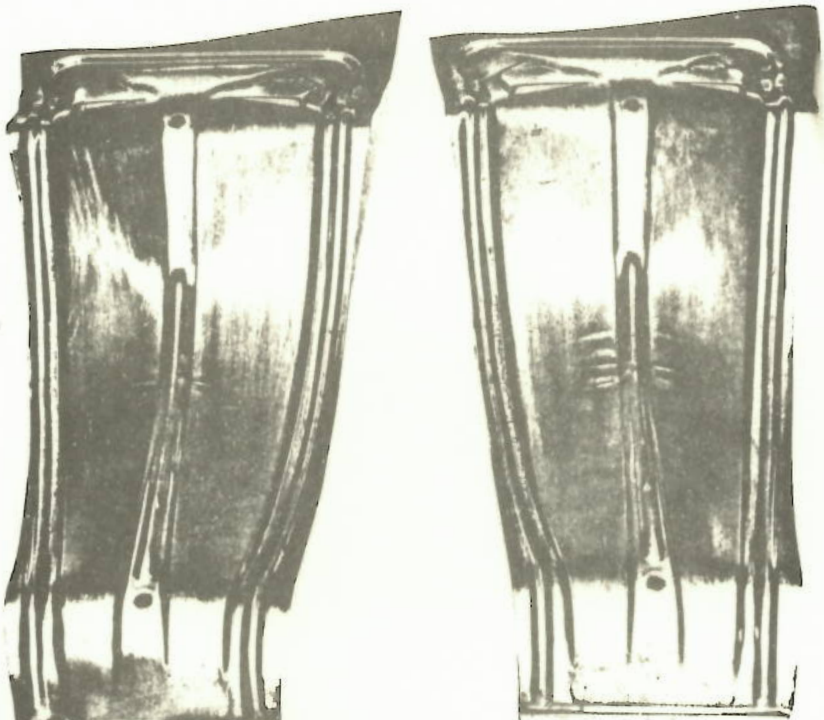

FIG. 2 GENERAL VIEW OF PRESSINGS;

(a) UNAGED STEEL
(b) AGED STEEL

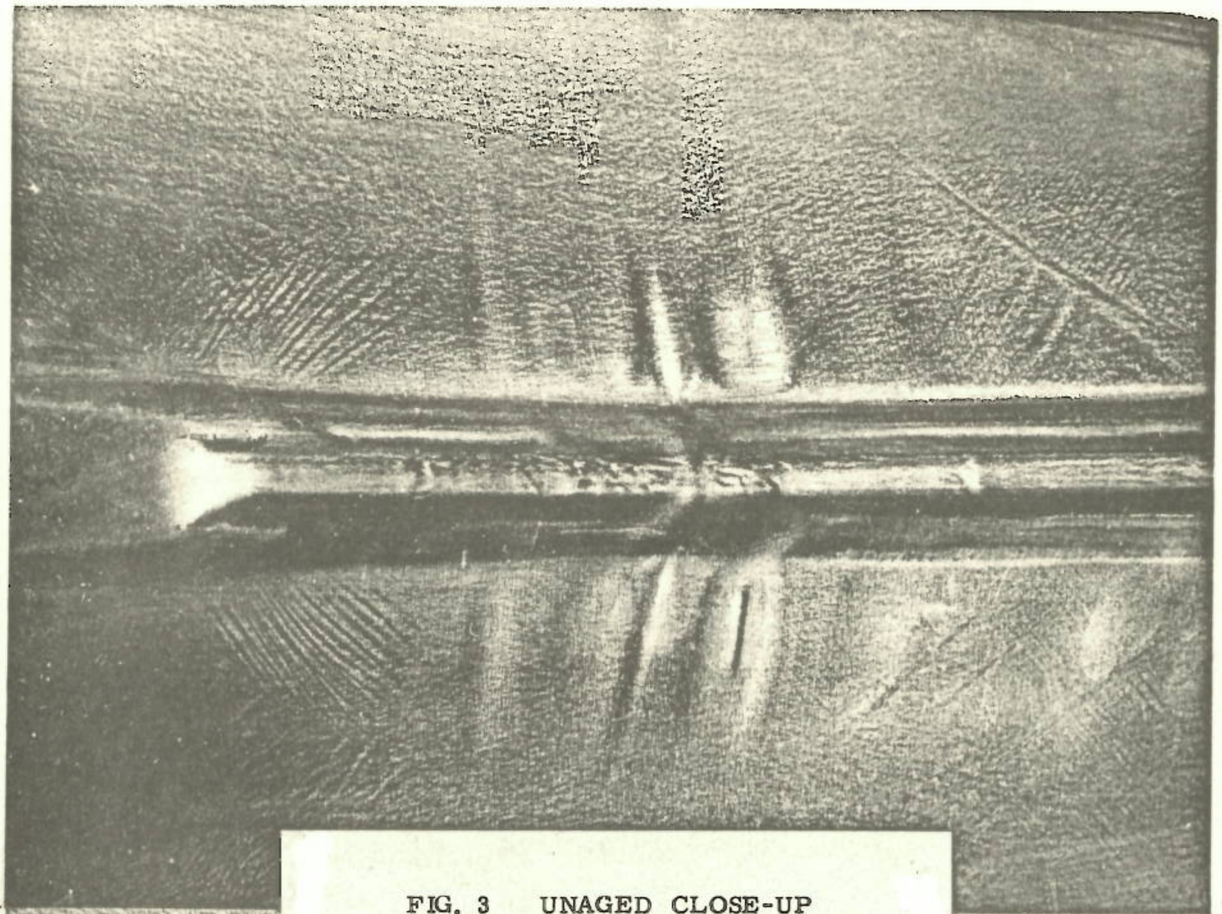

FIG. 3   UNAGED CLOSE-UP

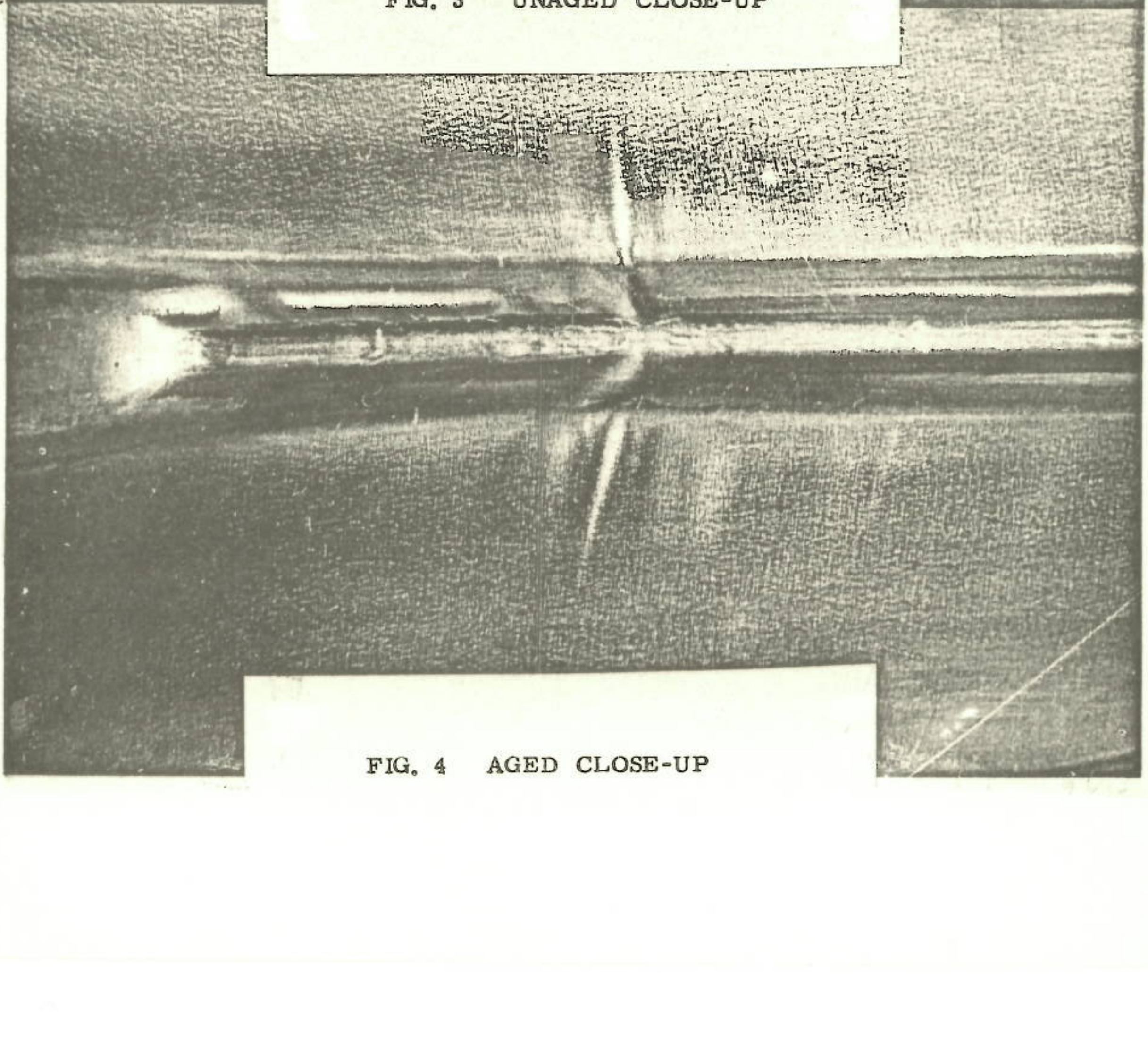

FIG. 4   AGED CLOSE-UP

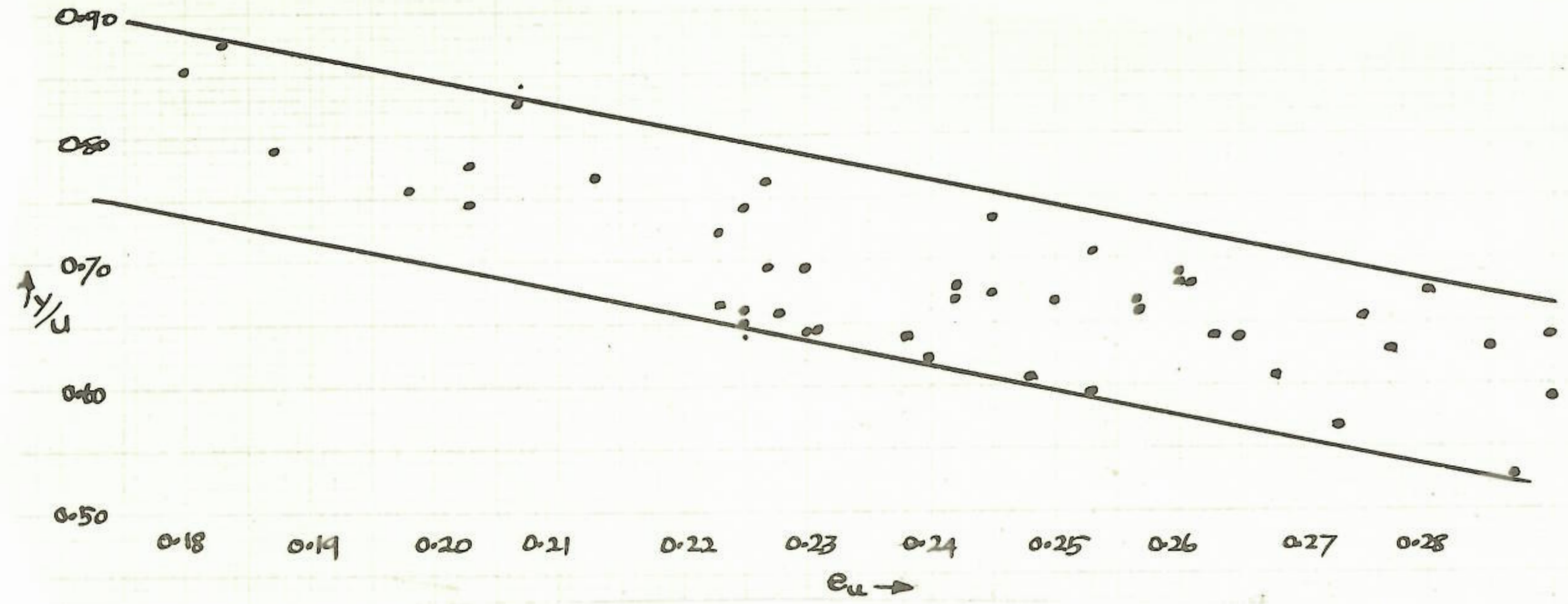

FIG. 5 RELATIONSHIP BETWEEN YS/US AND e_u FOR A NUMBER OF EDD STEELS

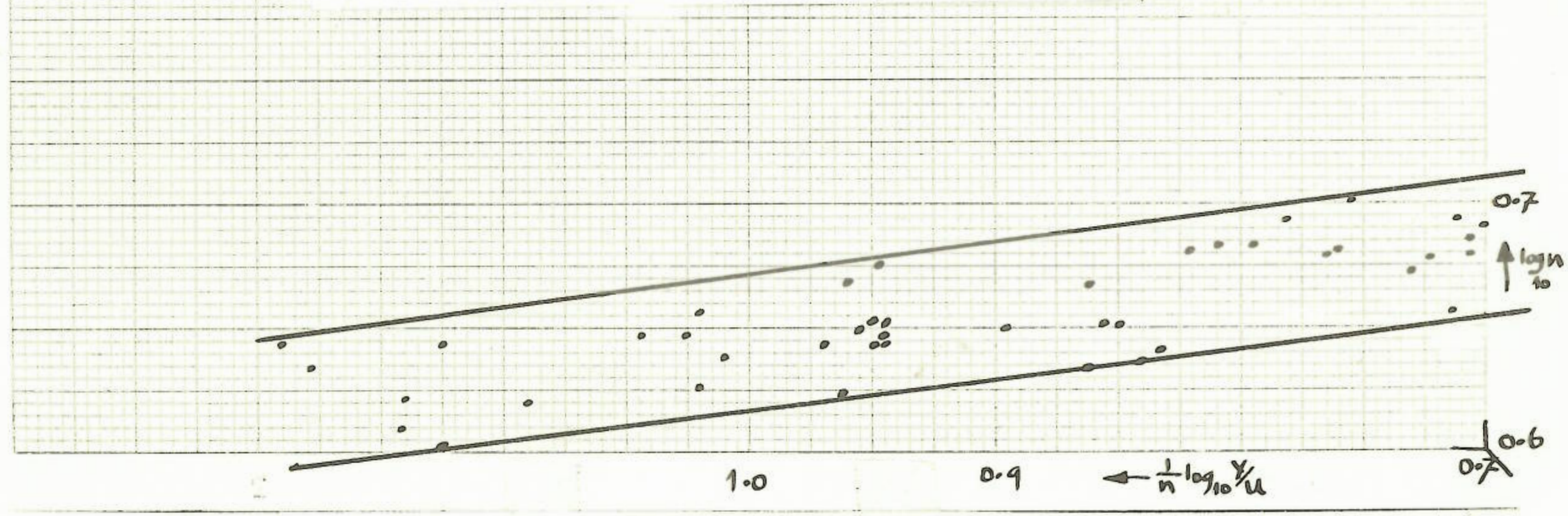

FIG. 6 RELATIONSHIP BETWEEN N AND YS/US FOR A NUMBER OF EDD STEELS

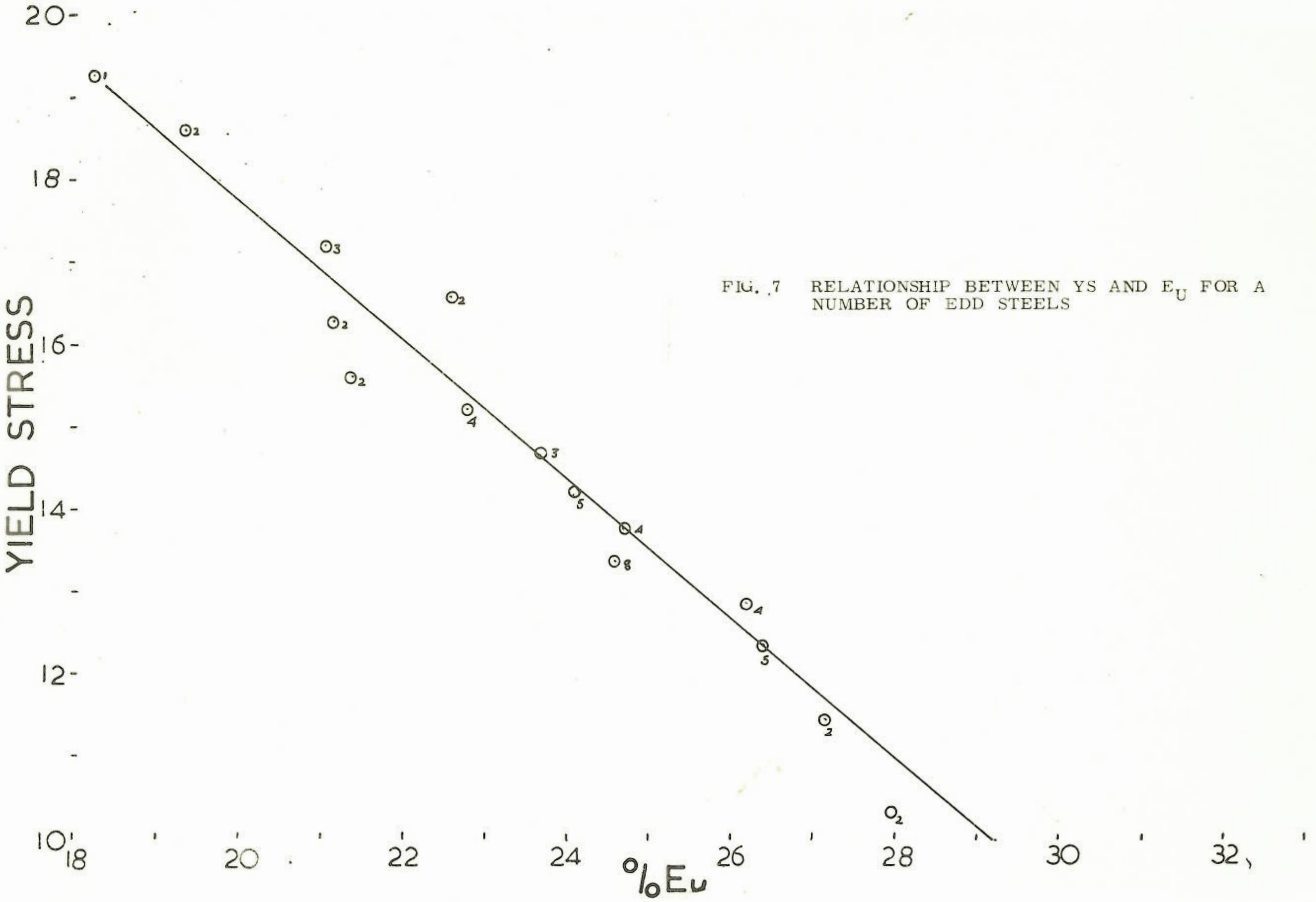

FIG. 7 RELATIONSHIP BETWEEN YS AND E_U FOR A NUMBER OF EDD STEELS

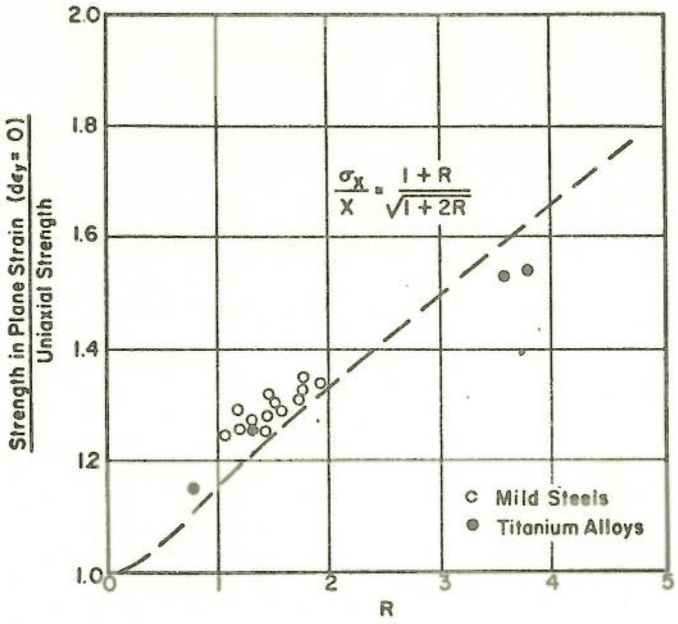

Fig. 8

Maximum strengthening effect of a state of plane strain as a function of normal anisotropy. Experimental points are based on the ratio of tensile strengths under plane strain and uniaxial stress conditions.

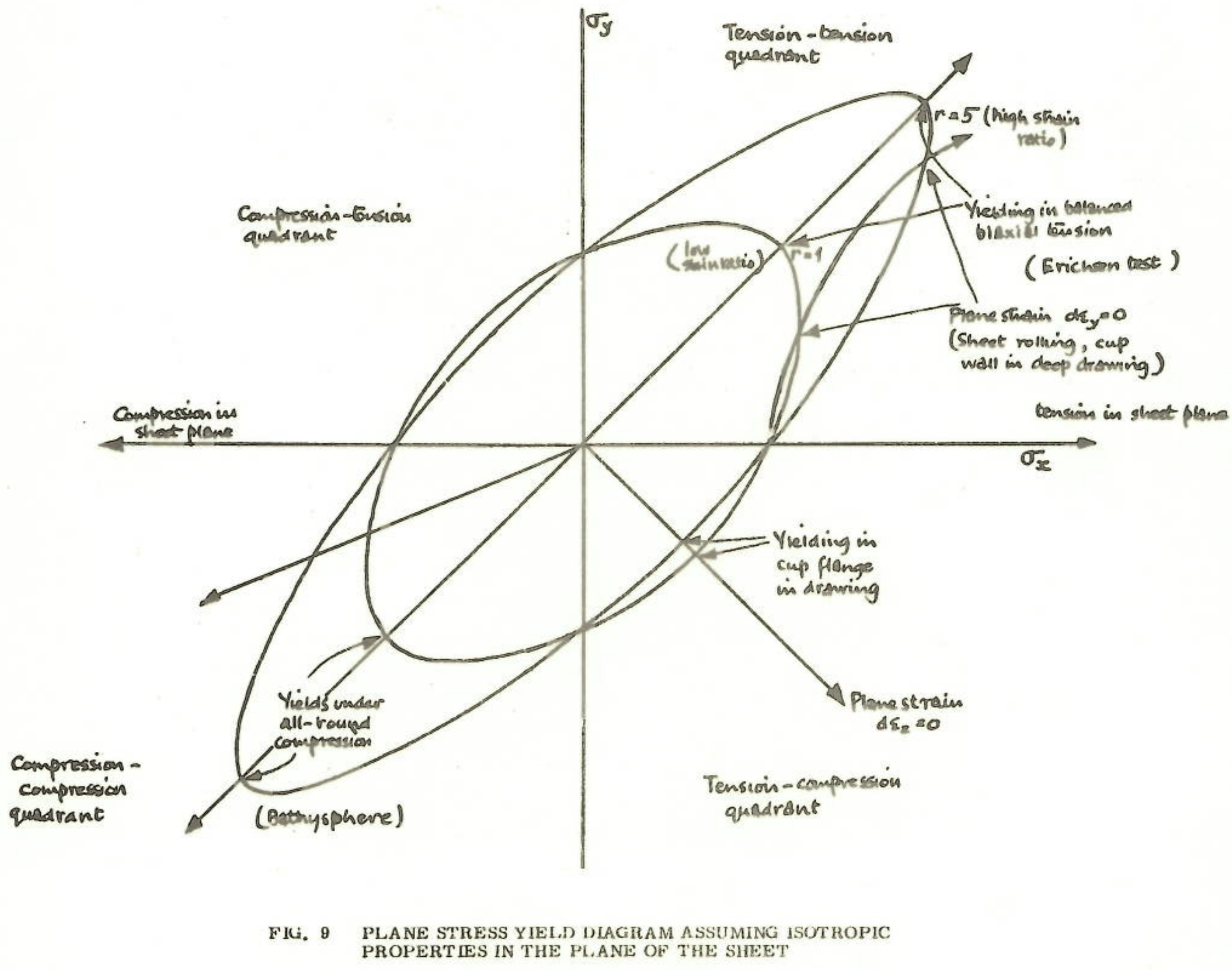

FIG. 9 PLANE STRESS YIELD DIAGRAM ASSUMING ISOTROPIC PROPERTIES IN THE PLANE OF THE SHEET