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THE IMPORTANCE OF TOUGHNESS IN MANUFACTURING

by
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Abstract

In manufacturing, the *yield strength* (*k*, Pa) of the material being worked determines how easy or difficult it is to achieve permanent deformation and hence the size of equipment required to do the job. In some processes, cracking of the workpiece sets limits, but in others such as slitting and trimming of sheets, can opening, guillotining, punching of holes and so on, separation of parts is required. The transition from plastic flow to cracking is controlled by the *fracture toughness* (*R*, J/m^2) of the workpiece, which is a measure of the resistances to crack initiation and propagation in tension and in shear. R is employed in the discipline of fracture mechanics. There are standard ways independently to measure fracture toughness, and it is to be emphasised that R is *not* the same as Charpy values. Furthermore, fracture mechanics applies not only to structural integrity linear elastic cases, but describes cracking in the presence of large irreversible deformations as found in forming. Processes may start as flow (controlled by the laws of elastoplasticity) but then become simultaneous combined flow and fracture (controlled by the laws of elastoplastic fracture mechanics).

The initiation of cracks may set limits on processes, and there are many empirical criteria written in terms of stress and/or strain that give limits for different forming processes. However, they are not transferable from one process to another — even for the same workpiece material — but they can all be rationalised when expressed in terms of workpiece toughness, a mechanical property that also determines whether the cracks are formed in tension or in in shear. Furthermore, in those processes where a number of cracks form, it is toughness that determines how many appear: a criterion of a critical strain at fracture, say, will simply predict *when* cracking will commence.

'Separation' is fracture by another name and such processes operate beyond the limits of normal forming. The modelling of all types of cutting (whether algebraic or FEM) should include toughness. Indeed, toughness defines what constitutes a sharp tool. Many experimental observations for which traditional 'Ernst-Merchant' theories have no explanation become quantitatively clear when fracture toughness is incorporated. These include workpiece-dependence of the angle of the primary shear plane, and transitions between different types of chip at different uncut chip thicknesses which are the result of *cube-square scaling* inherent in all fracture problems. That is, the remote work stored elastically or dissipated plastically over the whole workpiece depends on volume, but the work required for fracture depends only on the area of the cracked surface with its boundary layers of highly damaged, and separated, material above and below. Some metal cutters do not believe that fracture can have anything to do with cutting since 'cracks are not seen ahead of the tool'. In consequence artifices such as adaptive re-meshing are employed in FEM to simulate cutting without a criterion for separation, but that methodology does not represent the physics of what's happening at the cutting edge, and it also confuses the *existence* of cracking with the *stability* of cracking. Better to simulate all manufacturing problems with codes that will show fracture if that is what the physics demands, yet not show fracture if it is not part of the problem.

Energy scaling poses the fascinating question of what do we really understand by the classifications of 'brittle' and 'ductile' as determined by the behaviour of laboratory-size testpieces since glass, for example, can be machined with continuous ribbons at micrometer depths of cut, and ductile metals will split at very large depths of cut. It all comes down to the toughness-to-strength (R/k) ratio.

KEY WORDS: fracture toughness, forming limits, separation, cutting, cube-square scaling

List of symbols

A	area of the crack
E	Young's modulus