FRACTURE IN VOLUME COLD FORMING DIES

M. A. R. V. Fernando

1. Introduction

It was known for a long time that the possibilities of volume forming are limited not by the formability of the formed materials, but by the strength of tools. During cold forming of steels, particularly during cold extrusion, pressure inside dies reach very near the values of ultimate strength of materials with which tools are made, (200 - 300 Kp/mm²). Thus in the design of tools much attention has to be given, in addition to wear conditions, to the ability to withstand such high stresses without fracture or failure. A die may be put out of service due to wear or premature failure due to fracture.

2. Fracture of Dies

There are two main types of fractures, viz., Longitudinal (or axial) and Transverse. Longitudinal fracture is usually the result of overstressing. Load capacity of a die could be increased by radial prestressing of the die insert using stress rings. Methods of calculation of prestress were based on Lame's theory, though different yield criterii might have been used. Invariably all these methods, at least in the calculation of interference between insert and rings (or between rings), neglected axial stresses.

3. Overload Fracture

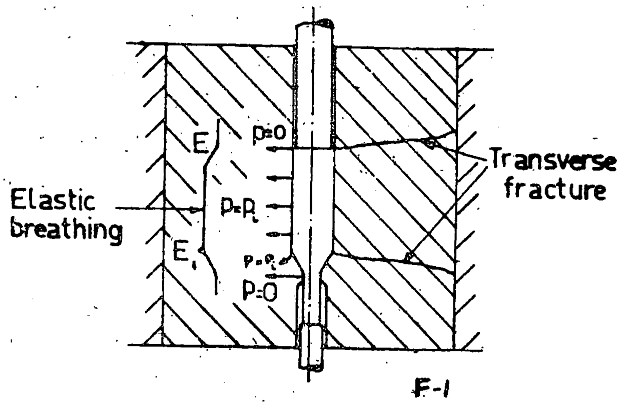
Over stressing which cause longitudinal fracture may result from insufficient prestress or too high an internal pressure. When insufficient prestress is suspected, it is necessary to check whether the designed interferences were really obtained in making the die assembly and whether the prestress could not be increased by: (a) Increasing the overall diameter of the assembly, (b) Using additional stress rings, (c) Using stress rings of higher strength. Assuming the extrusion operation being performed properly, too high an internal pressure may be caused by too high a flow stress of slug material due to variation in material composition or insufficient annealing and/or surface treatment.

With multi-ring stressing and giving due consideration to the above factors, longitudinal cracks could be avoided to a very large extent. Unfortunately the Transverse Fracture represents a further danger to highly stressed dies and cannot be countered by radial prestressing.

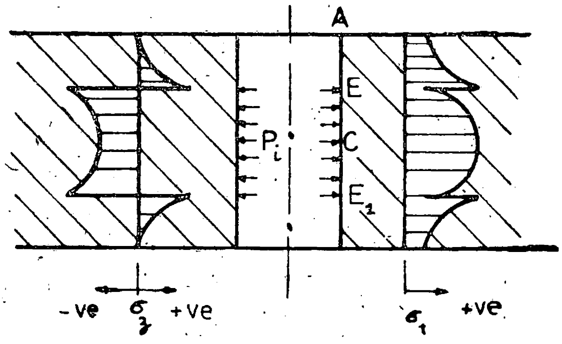
4. Transverse Fatigue Fracture (T.F.F.)

This transverse fracture is frequently observed in one piece rods or tube extrusion dies, and sometimes in reinforced die inserts too, particularly with hard metal inserts. This usually occurs in the vicinity of die shoulder entry, and sometimes at locations corresponding to position of rear face of slug at the end of extrusion operations. The form of crack clearly shows occurrence of a fatigue fracture as distinct from an overload.

This was earlier supposed to be due to so-called "Breathing Effect". High pressure inside the die bore falls to zero, almost instantaneously along punch face, and rapidly along the extrusion taper, during forward extrusion. This internal pressure in only a limited portion of the die bore causes elastic expansion (elastic breathing) at the pressure zone of the core. This elastic breathing during each stroke was supposed to be leading to material fatigue and occurrence of annular transverse cracks, starting at the point where elastic elongation curve kinks Fig. 1. Additional notch effect at throat cause this fracture to occur primarily at this transition zone.



F-1



Earlier, this elastic breathing was supposed to be an inevitable and inherent evil. Thus, certain remedial measures that were adopted are: (a) limiting internal pressure to a level where commencement of fatigue fracture coincides with wear life of the die. (b) Use of tougher materials, thus sacrificing better wear resistance. E.g., tool steels instead of sintered carbides, or decreasing hardness of tool steels by 2 to 5 points on HRC series, if it could be tolerated. (c) Splitting the die, axially or transversely.

TFF could be delayed considerably by this splitting and was earlier the best solution as other methods sacrifice either tolerable internal pressure or wear life. Thus in short, harder grades of sintered carbides or tool steels at higher hardness levels, with better wear resistance properties, could not be used to their best advantage, earlier, due to this TFF.

5. Present Explanation of T.F.F.

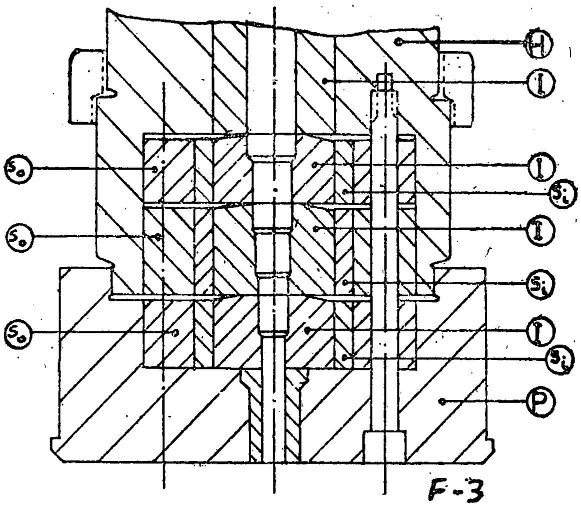
Kudo et al[1] in 1970, analysed by numerical methods, using an electronic computer, the stress distribution of a die due to an internal pressure in only a limited length of the die bore. Their analysis showed, that in the zone where pressure is acting in the bore, there exists a compressive axial stress in the insert, which becomes tensile immediately outside the pressure zone (Fig. 2). This effect is most prominent at the bore surface of the insert and dies off rapidly across the cross-section. The tensile component of the axial stress thus developed, during each stroke, leads to fatigue failure of the insert, fracture starting at the bore surface and propagating radially outwards. According to both Tresca's and Misse's criterii of yielding, the most dangerous point is C, (Fig. 2), where σ_θ is positive and σ_r is negative (just outside E and E', even though σ_θ may be higher than at C, σ_r is zero), and not E or E'. But in practice transverse fracture is observed at E and E', showing that this is due to fatigue caused by the tensile component of axial stress developed.

6. The Effect of Partitioning of Die

The effect of an axial split of a die as a measure against TFF could be explained better with the new stress analysis. The inner part of the insert is usually prestressed by warm shrinking with much interference as possible, or sometimes force fit with slight taper may also be used. Considering outer part of insert, two radial forces are acting on inner surface, one due to prestress with inner part of insert and other due to internal pressure (or load) at the bore. By analysing these two components separately and according to new analysis, and then summing up the two components, it could easily be shown that the axial stress at throat may be fully, or at least to a great extent, prevented from becoming tensile. Stress distribution in inner part of insert too becomes much favourable. In addition to radial reinforcement due to interference with outer part, extrusion pressure imparts a favourable axial compressive stress in the inner part of the insert, which is higher, larger the included angle is. This is suitable for high angled dies, and is found in practice to be particularly effective for dies with included angle over 90°. Further advantage of both axial and transverse split is that notch effect too, at the bore surface at throat, is eliminated. But, both these methods could combat TFF at the lower critical point only.

7. How to Avoid Tensile Axial Stress Component

7.1 Now the question arises whether this dangerous tensile component of axial stress could be avoided, and if so, how? Let us consider the effect of superimposing an axial compressive stress on the insert by some means. Then the stress pattern will be shifted to compressive direction as a whole unit. If the imparted compressive stress is sufficiently high, axis may be shifted far enough to make axial stress at all points compressive, thereby avoiding the TFF. Infact, even a partial countering of tensile component of axial stress, just sufficient to make fatigue life coincide with wear, would be enough.



F-3

I - Inserts
S_i - Stress rings (inner)
S_o - Stress rings (outer)
H - Holder
P - Holder / pressure pad

7.2 Now, how is this compressive stress imparted? This may be accomplished by: (a) Post stressing of insert (i.e.: stressing after assembling insert with ring(s)). (b) Prestressing of insert (i.e. stressing of insert before, or during assembling with ring(s) or (c) Combination of both pre- and post-stressing.

8. Post Stressing

Several techniques may be used for axial post stressing of a die insert, e.g.; by powerful clamping of die insert, or die, in axial direction or by mounting it in a die sleeve with a screw in pressure pad or by a bolted assembly. Contrary to certain claims, the merit of this method as an effective way of imparting an axial compressive stress in the insert is questionable. External force applied, though applied only through insert, will be shared both by insert and ring(s). Thus, effective stress imparted on insert will be small except at the immediate vicinity of application of force. For example, for a die of diameter ratio of 4 (i.e. D/d = 4) with an interface diameter of twice bore diameter, where an internal pressure of σ_r is acting at bore, it can be shown that an axial stress of about 0.4 σ_r would be required to completely eliminate the tensile component of axial stress developed due to internal pressure. If that axial post-stress ($\sigma_z = 0.4\sigma_r$) is attempted,

M. A. R. V. Fernando, B.Sc. (Eng.), Ph.D., graduated from the University of Ceylon in 1968. He worked in industry, including Ceylon Steel Corporation, for a few years before proceeding to do his post-graduate research studies in Metal Forming Engineering at the Technical University of BRNO, Czechoslovakia, and was conferred the Ph.D. degree in 1974. At present he is attached to the National Engineering Research and Development Centre of Sri Lanka. He is also a visiting lecturer at the Department of Production Engineering, Faculty of Engineering of the University of Sri Lanka, Peradeniya Campus

assuming same E for both ring and insert, axial stress at the immediate vicinity of application of external force (σ_z^*) will be five times that of inside, $(\sigma_z^* = 5\sigma_z = 2\sigma_r)$, which may even lead to plastic deformation at that zone. If, on the other hand, applied force is restricted to safe limits, then axial stress effective on insert will be too small and would obviously be inadequate. Further, this method could be used only if other considerations such as geometry, space etc., permits it. Yet, with all these drawbacks, it is claimed that post stressing with powerful clamping has increased die life by about 20%.

9. Prestressing

This could be subdivided into two categories. (a) Automatically, (or self) induced axial stress, if any, as a result of obtaining interference fit. (b) Any axial stress, or enhancement, purposely imparted by some suitable technique.

9.1 A technique developed recently—pending patent—utilises stress rings not only to impart radial prestress, but axial prestress too. Even when thermal means are used to obtain the interference fit, usual methods of calculations—other than that published in ref. 2—ignore any axial effects (to the best knowledge of author), and assume that stress rings contract only in radial direction. But in reality, they do contract in axial direction too, thereby imparting a compressive prestress in insert, the axial force involved being transmitted through interface of ring and insert.

9.2 If a compressive axial stress is kept operative on insert, by suitable external means, e.g., ram force of a press, while shrinkage union between ring(s) and insert is taking place, the automatically—or self-imparted compressive axial stress in insert could be enhanced. Imparted stress could be well controlled by controlling the operative axial force and could be precalculated.[2]

9.3 In case of taper and force fit, required axial compressive prestress could be imparted to the insert by forcing (pressing) insert into ring and, after pressing the distance required for interference requirements, against a base block. The base block is to be placed at a distance so adjusted to get the depth of penetration required for interference before the insert gets pressed against the block—pending patent. In the case of combined thermal and force fit too, same technique could be employed.

9.4 Advantages of both pre- and post-stressing could be combined in certain cases, for example, if design and geometry warrants, by use of already prestressed components in a transversely split and post-stressed assembly. Fig. 3.

10. Complete elimination of TFF, or its postponement to coincide with wear life, will enable the use of much harder, and less tough, materials with better wear resistance properties, such as harder grades of sintered carbides or tool steels at much higher hardness levels than that commonly used at present, in die inserts, thereby increasing the useful life of dies (and die assemblies). Though multi-ring radial prestressing prevented longitudinal fracture, the allowable internal pressure at the bore of a die (load capacity), yet, was limited by, or due to, transverse fracture. Thus, suppression of TFF by these methods will ease limitations on load capacity of dies (and die assemblies).

Experiments have shown the practicability and effectiveness of axial prestressing, both natural and enhanced, of dies. Calculation of dies (and die assemblies), when axial prestressing is to be used much differ from standard methods of calculations and results may even be catastrophic if axial prestressing is attempted with dies calculated according to methods which do not take axial stresses into account. New method of calculation suitable for use with axial stressing is given in reference 2.

References

1. Kudo H, Yokohama, Sh. Matsubaya: *Analyse der Spannungen in Zylindrischen Werkzuegen enlich lange, die einer inneren Druckspannungsverteilung ausgesetzt sind*, Industrie Anzeiger, 92 Jg. Nr 30, pp. 631.634.
2. V. U. T. V. Berne, *Improvement of Calculation and Construction of Dies for Volume Cold Forming*, Dissertation, August 1974, pp. 43-75.

සංක්ෂිප්තය

ශීත මූර්තිකරණ කෝෂ්ඨයන්ගේ බිඳුම්

ලෝහ මූර්ති කරණ කෝෂ්ඨයන්හි අතිබර බිඳුම මුදුඅනු සාරයෙන් තීර්යක්ව පෙර ප්‍රෂ්‍යා බැර කිරීමෙන් (Multiring radial prestressing) සඵලදායක ලෙස මැඩ පැවැත්විය හැකි වුවද, අතිශයින් බර පටවන ලද කෝෂ්ඨයන්හි දක්නට ලැබෙන තීර්යක් ආයාස බිඳුම ප්‍රශ්නයක්ව පැවැතින. මෙය (breathingeffect) නමින් හැඳින් වෙන ඵලය නිසා සිදු වන්නේයයි මුලදී සිතන ලදී. කෝෂ්ඨයන් බෙදීම වැනි යොදන ලද ප්‍රතිකර්මයන් අඩ විසඳුම් පමණි. කෝෂ්ඨ සිදුර තුල අති පීඩනය හේතුවෙන් ඇතිවන අක්ෂික ප්‍රශ්‍යාබලයෙහි අකෘත්‍ය කොටස මෙම බිඳුමට හේතුවන බව පසුව පෙන්වා දෙන ලදී. පසු ප්‍රශ්‍යා බැර කිරීම් ප්‍රයෝජනවත් වුවද, සඵලදායක විසඳුම් යයි සැලකිය නොහැක. තීර්යක් වලට අමතරව අක්ෂික ලෙසද පෙර ප්‍රෂ්‍යා බැර කිරීම සඳහා මුදු පාවිච්චියද එමගින් තීර්යක් ආයාස බිඳුම් නැවැත්වීමද නව ආකල්පයකි. වැඩි හොඳ නොගෙවන ගුනාංගයන් සහිත වැඩි දෘඩ නමුත් අඩු (tough) ද්‍රව්‍යයන් කෝෂ්ඨයන් හී ඇතුල් කොටසට (insert) පාවිච්චි කිරීමේ හැකියාවත් කෝෂ්ඨයන්හි බරපැටවීම සඳහා තුබූ සීමා ලිහිල් කිරීමේ හැකියාවක්, එමගින් කෝෂ්ඨයන්හි ප්‍රයෝජනවත් ජීවිත කාලය සහ බැර පැටවීමේ හැකියාවන් දියුනු කිරීම, මෙම තීර්යක් ආයාස බිඳුම මැඩ පැවැත්වීම නිසා හැකිවේ.