Selecting Optimum Interference Fit in Tool Assemblies using Die-Press and Simulation Software

Dr. Vijay Nagpal,
Metal Forming Systems, Inc.
7974 Lilley Road, Canton, MI USA
www.nagform.com

The tooling used in cold forging is subjected to very high stresses due to the high strength of the metal when deformed at ambient temperature. To withstand this high pressure exerted by the deforming metal, in some applications, the tooling is made of multiple components fitted together using interference fit. Design of these tool assemblies is very critical as it determines the life of the tool components. In this article, we are presenting an approach to select the optimum interference in a two-component assembly. One objective of the selection of interference is to allow as high an internal forging pressure as the assembly can be designed for. Another equally important objective is to get the maximum tool life possible for the components.

Basics of Interference Fit

To understand the principle of interference fit, let us take a simple tool of the shape of thick cylinder that is very long. Using the classical theory of a thick cylinder with no elongation in length direction, the stresses in the tool due to internal pressure are given by:

$$\sigma_t = \frac{Pi}{\frac{Ro^2}{Ri^2}-1}\left(1+\frac{Ro^2}{R^2}\right)$$

$$\sigma_r = \frac{Pi}{\frac{Ro^2}{Ri^2}-1}\left(1-\frac{Ro^2}{R^2}\right)$$

Ro = Radius of Outside Dia
Ri = Radius of Inside Dia
R = Radius at any point
Pi = Internal Pressure
σ_t = Tangential Stress, Tensile
σ_r = Radial Stress, Compressive

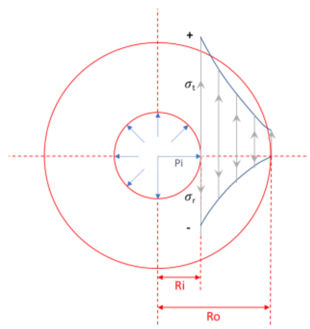

Figure A: Internal and External Stresses in tool

The tangential stress is tensile and highest at the bore. The radial stress is compressive and is also highest at the bore. For a thick cylinder, the effective stress, a composite of the multiaxial stresses, is given by

$$\sigma_{eff} = .866\ |\sigma_t - \sigma_r|$$

This definition of effective stress is due to 'Von Mises' who postulated that in a multiaxial stress state, the material yields when the effective stress reaches the value of yield stress determined using a uniaxial tensile test. There is another definition of effective stress due to 'Tresca' which says that the effective stress is equal to the maximum difference between the three principal stresses. For a thick cylinder, the effective stress due to 'Tresca' is given by

$$\sigma_{eff} = |\sigma_t - \sigma_r|$$

The effective stress is also maximum at the inside bore of the thick cylinder. Because the tool is hardened to a high hardness, it deforms only a little beyond the yield stress and breaks. If the internal pressure exceeds a certain value, the tool breaks, splitting in the length direction.

If an external pressure is applied, it puts compressive tangential stress at the bore which reduces the effective stress at the bore. The thick cylinder can withstand greater internal pressure if an external pressure is applied. This is the principle used in a two component assembly of the tool. The interference fit puts external pressure on the inside component called insert but puts internal pressure on the external component called casing. In the casing, the tangential stress increases. The design of the two-component assembly must be such that neither insert not casing yields due to internal pressure. The two-component interference fitted assembly can withstand much higher pressure than a single component tool.

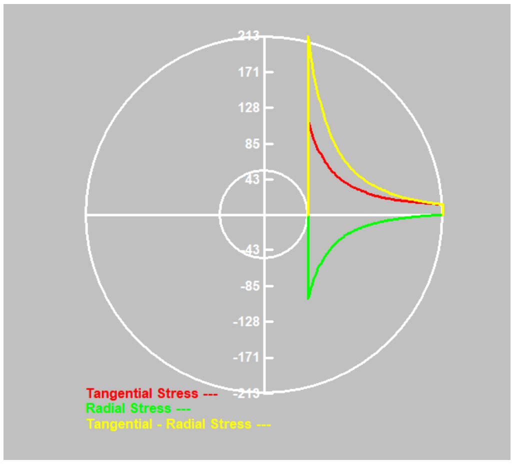

Figure B: DiePress Software results for a Single Ring cylinder

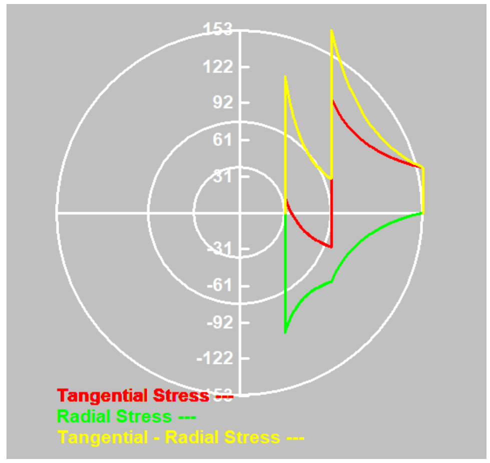

Figure C: DiePress Software results for a Two Ring Die Assembly

The same principle of reducing the effective stress in insert is employed in a three-component tool assembly. Here, the casing is split into two components, a mid-insert and a casing. It can be shown that a three-component press fitted assembly can withstand even higher internal pressure than a two-component assembly for the same space available for the tool.

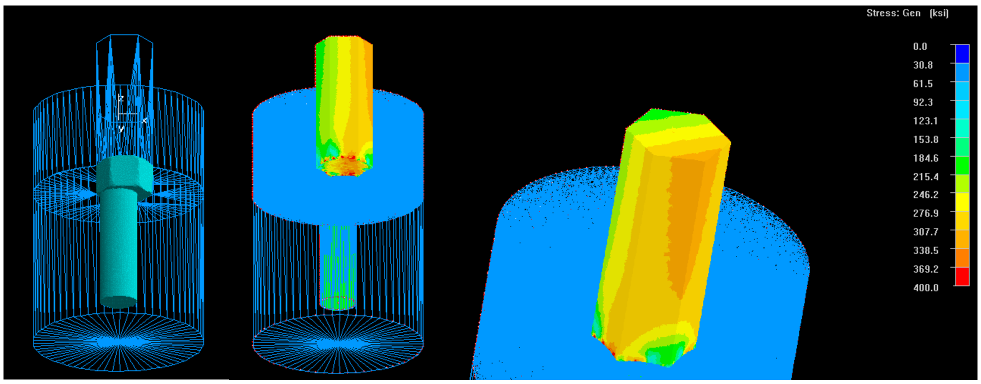

Figure D: Stresses in a Hex Punch from an Off-Center Hex Heading Operation

Limitation of Interference Fit

It should be noted that interference fit only helps to reduce the tensile tangential stress which causes longitudinal cracks. It does not help in reducing transverse cracks. To reduce the transverse cracks, the die insert is sometimes split along the length. The effect of other stresses in the insert due to e.g. a forging load on the end face of the insert is not reduced by the interference fit.

Role of FEA Simulation

The stresses in thick cylinders can be predicted with reasonable accuracy using classical methods of analysis. However, in real cold forging applications, the insert does not have single straight bore and is not very long. The stresses calculated using classical equations of a thick cylinder may not give accurate prediction of stresses. Also, the forging pressure inside the tool varies during the forging cycle. It cannot be predicted accurately without FEA simulation.

FEA simulation of forging process and analysis of tool stresses is the only method that can accurately predict (a) forging pressure acting on the inside surfaces of the tool and (b) stresses in the tool due to the forging pressure and the interference fit.

Die-Press software program which uses classical equations of thick cylinder can be used as a starting point for determining the interference fit. However, the design needs to be fine-tuned using FEA simulation.

Tool Life limited by Fatigue

In a cold forging operation producing parts, the tools mostly fail by wear or by fatigue. Metals fail by fatigue when subjected to repeated application of fluctuating stresses. The stress level is less than the yield strength of the tool material, still the tool fails due to alternating stresses. For any material, the number of cycles to fail depends upon the amplitude of the stress defined as ($\sigma_{max} - \sigma_{min}$)/2.0 and the mean stress ($\sigma_{max} + \sigma_{min}$) /2.0 . For the same stress amplitude, the number of cycles to fail is less when the mean stress is tensile compared to compressive.

The endurance limit is defined as the stress amplitude below which the tool material may never fail or the number of cycles is more than one million.

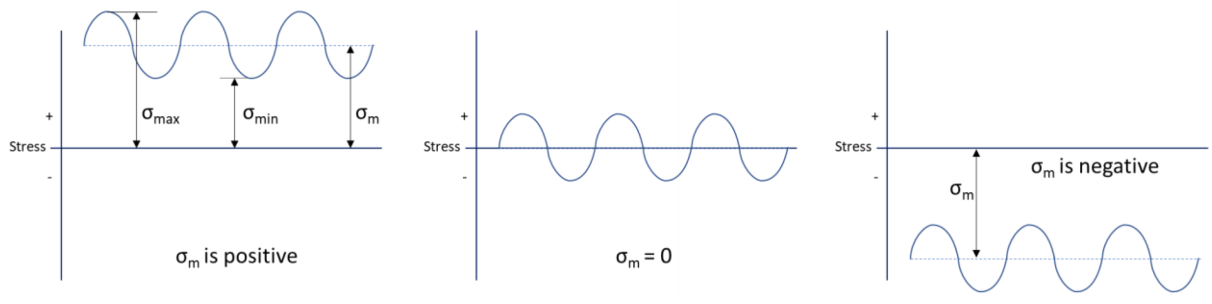

Figure E: Fluctuating Stresses – Mean in Compression and Tension

Yield Strength of Hard Tool Materials

In cold forging, tool materials used in forming are different grades of carbide and hardened high speed steels. The yield strength of these tool materials, in general, is less in tension than in compression as shown below for some materials. For carbides, their yield strength in tension is much lower than their yield strength in compression. Carbides tools need to be in compression in cold forging operations.

MATERIAL	HARDNESS	YIELD STRENGTH IN TENSION, PSI	YIELD STRENGTH IN COMPRESSION, PSI	MODULUS OF ELASTICITY, PSI	POISSON'S RATIO
H13	46-49 RC	206,000	260,000	30,500,000	0.29
Carbide					
K3833 - 11% CO	89.4 RA	178,000	705,000	81300000	.28
K3109 - 12% CO	88.0 RA	182,000	635,000	82200000	.28
K3520 - 20% CO	84.0 RA	205,000	530,000	70300000	.23
M4 (RC 62-64)	RC 62-64		424000	28000000	.29

How to Select Optimum Interference Fit in Tool Assemblies

The optimum interference fit in any tool assembly need to satisfy the following criteria:

1. The effective stress in the tools, insert and casing, should never exceeds the yield strength of their tool material during the cycle.
2. The interference fit should put the insert in compression throughout the cycle.
3. The amplitude of effective stress at any location of the tool during the cycle is minimum so the tool may have maximum fatigue life

The procedure to find the optimum interference is as outlined below. It uses both the Die-Press software and the FEA simulation program NAGSIM.

- In principle, put an interference that causes a compressive tangential stress at bore of the insert equal to or more than the tensile tangential stress there due to the forming pressure
- In net, the insert would have a compressive tangential stress when no part is being formed and a nearly zero or compressive tangential stress during forming.

1. Perform a simulation for tool stresses assuming no interference fit. Then determine from results (a) maximum forming pressure and (b) tangential and efefctivestresses at inside bore surfaces of the insert and the casing

2. Determine the interference fit which would give compressive tangential stress equal to max. tangential stress at insert bore determined in above (1)
3. Determine the tensile tangential stress and compressive radial stress at inside surface of the casing from the interference pressure. Add to tangential and radial stresses there without interference fit. This would give estimated combined stresses with interference fit and forming pressure.
4. Calculate $\sigma_{eff} = .866\, |\sigma_t - \sigma_r|$ at casing inside surface. Its value should not exceed yield strength of casing material which is usually H13 at RC 47-49. The yield strength is around 225,000 psi
5. If σ_{eff} exceeds, reduce the interference amount and recalculate step 4. Do this till σ_{eff} at casing inside is < 225,000 psi.

Example – Cold Forging of Ball Stud

As an example, cold forging of a ball stud is considered to illustrate the procedure of finding the optimum interference fit. Only the die assembly used in first operation for extruding the smaller end is analyzed.

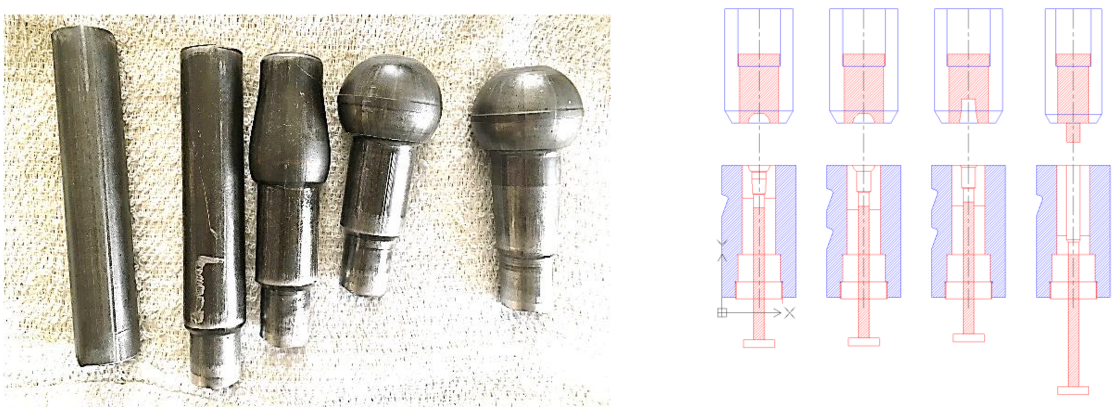

Figure F: Part Progression and Tool Layout provided by PRF Manufacturing Roseville MI

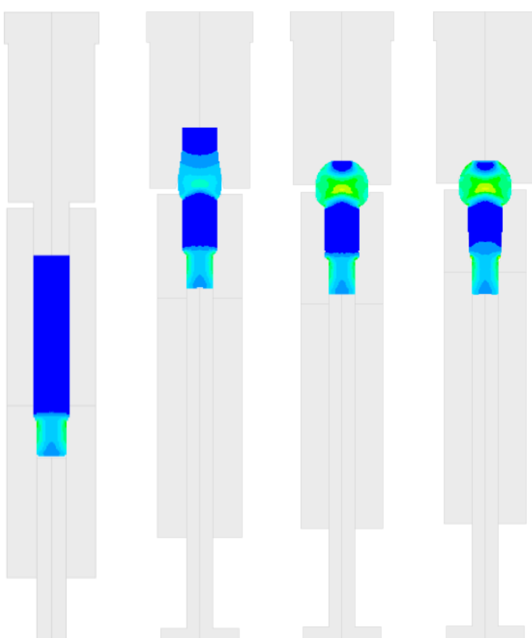

Figure F: NAGSIM.2D Simulation

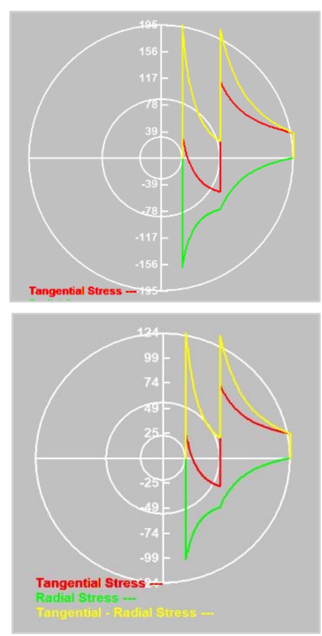

Figure G: Calculation of Interference for the 2 die Inserts

- The sequence design and volumes were checked using NAGFORM software for sequence design.
- The simulation without interference fit was performed using NAGSIM.2D.
- From the results, the radial, tangential and effective stress values were determined. Using the DiePress software, interference fit values for the top and bottom dies which would make the tangential stress compressive were calculated.
- The FEA simulation with the press fit were performed. The comparison before and after are shown below.

	Tool	Before (ksi)	After (ksi)
σ_{11} (Radial Pressure)	Die 1	-80	-80
	Die 2	-200	-200
σ_{33} (Tangential Stress)	Die 1	+130	-30
	Die 2	+80	-120
σ_{eff} (Effective Stress)	Die 1	200	100
	Die 2	325	225

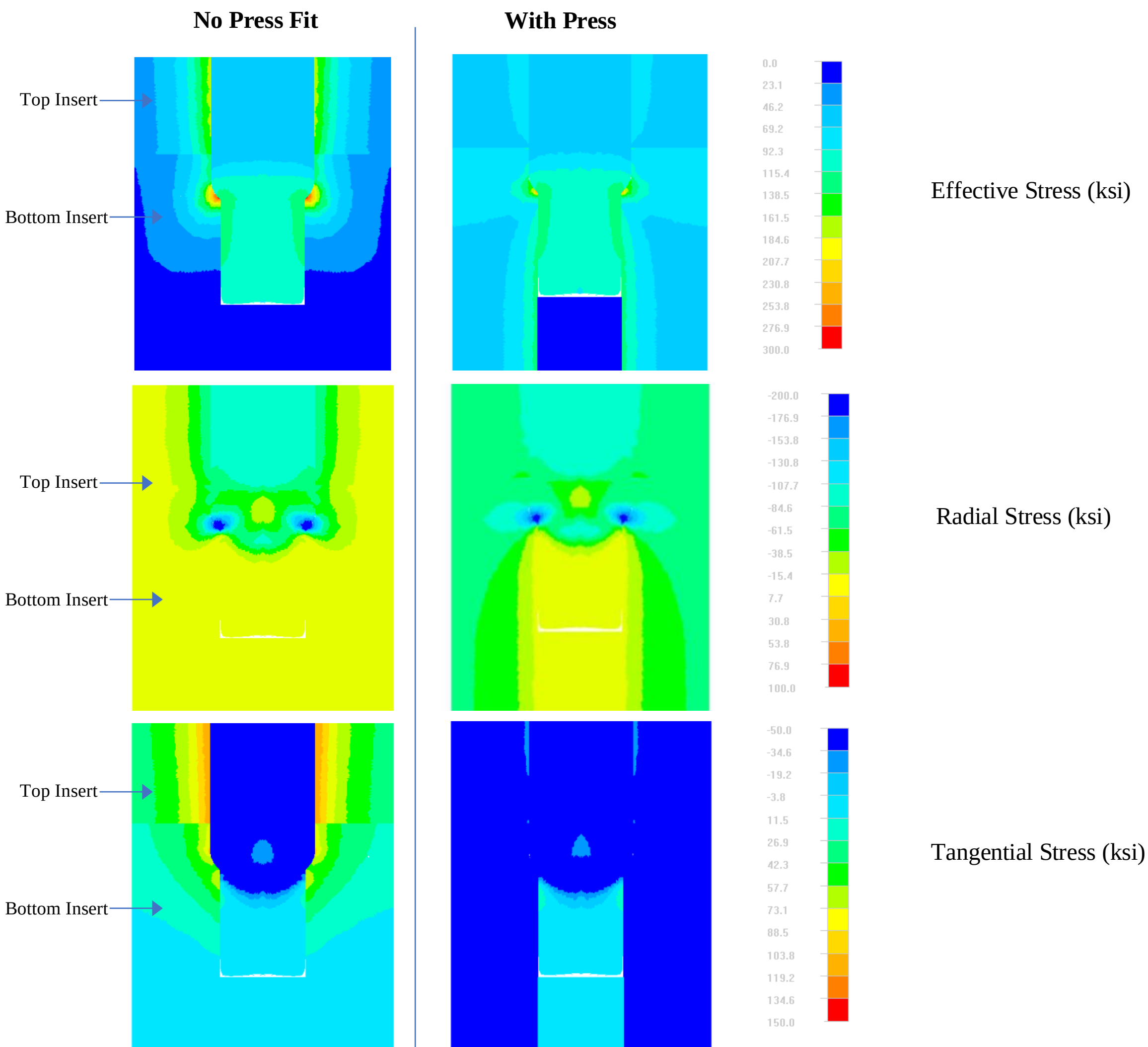

Figure H: The Stresses σ_r, σ_t, σ_{eff} obtained from NAGSIM.2D simulation are presented here

Metal Forming Systems, Inc. develops and supplies process design and finite element analysis (FEA) simulation software for the metal forming industry. The software products include 'DiePress Calculator', 'NAGFORM' for Design of Forming Sequence and 'NAGSIM' for simulation of forging processes by Finite Element Method. For more information on these products, please visit www.nagform.com or contact us at (734)658-1716