FINITE ELEMENT SIMULATION OF BACKWARD EXTRUSION DIES USING SHRINK FITTED RINGS

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Abstract: It is necessary to make constructional changes on the dies for manufacturing of tubular mechanical elements by forward and backward cold extrusion in order to maintain high dimensional precision. The radial elastic deformations are controlled by inserting single or double shrink fit within the die. This arrangement decreases and homogenizes tangential stresses in the die and shrink rings and improve die fatigue life. A conventional way of calculating stress and deformation for this kind problem is Lame Equations. In this study, the effect of dimensional changes of die and shrink rings on the radial deformations occur in the internal surface of the shrink ring, U_{rr}, is investigated. The diameters of die and shrink rings are investigated in order to maintain preselected diametral tolerances. Under preselected process and design conditions the following results were found; for +0.1 mm. tolerance single die, for the tolerance value of 0.05-0.1 mm. single shrink ring and for the tolerance values below 0.05 mm. double shrink rings were necesssary. The theoretical results showed that beyond the radial ratios $r_2/r_1=4$ for single shrink design and $r_4/r_1=7$ for double shrink ring design the radial deformation curve, U_{rr}, becomes asymptotic and an increase in external diameter does not make any change. The results achieved by Lame Equations are compared with those of the Finite Element Method solved by Ansys Programme it is seen that the difference is generally up to 3 %. Also it is predicted that due to the external pressure introduced by shrink rings the radial deformations within the die towards the outer surface is zero. Hence, this results no crack on the outer surface of die and longer fatigue life.
Keywords: Backward Extrusion, Radial Displacement, Finite Element Simulation

1 INTRODUCTION

Cold Extrusion Method (CEM) has become a very important industrial manufacturing process. Most materials can be deformed or re-shaped within limits by applying suitable forces without disturbing or damaging inner structures. Aluminium and aluminium alloys, copper and copper alloys, low and medium-carbon steels, low-alloy steels, and stainless steels are usually processed by CEM. CEM competes with other metal forming processes such as hot forging, hot extrusion and machining, and sometimes with casting. CEM is suitable when the process is economically attractive because of:

- Savings in material
- Reduction or elimination of machining and grinding operations, because of good surface finish and dimensional accuracy of cold extruded parts.
- Elimination of heat treating operations, because of cold extruded parts.

The tools used for extrusion play an important role for trouble-free operation of the process in mass production. Design of the tooling, optimum use of the tool materials in conjunction with good prestressing of the die and accurate manufacture of tooling are all important factors for tool performance and required   tolerances of parts. The components of a typical tool assembly used for backward extrusion of steel parts are shown in *Figure 1.* There is a considerable variation in tooling practice and in the design details of tool assembly components.

In CEM, the die is under maximum pressure, and this pressure is not distributed uniformly. To provide reinforcement, extrusion dies are usually inserted in one or more shrink rings. These rings prestress the die in compression by providing interference fits between rings and die.

This results in lower working tensile stress and hence consequently longer fatigue life of extrusion tools. The tolerances in the tools should be such that at the beginning of the run the product is near its lower permissible dimensional limits. The tool may be allowed to expand in accordance with theoretical calculations. The tools should have the closest possible tolerances so to allow full advantage of the permitted tolerances to be taken. As a rule, the tool tolerances should be less than 10% of that of product. To keep the expansion of die to be the minimum in order to obtain the better possible tolerances. It is advisable to use correct shrinking and radii of rings [2].
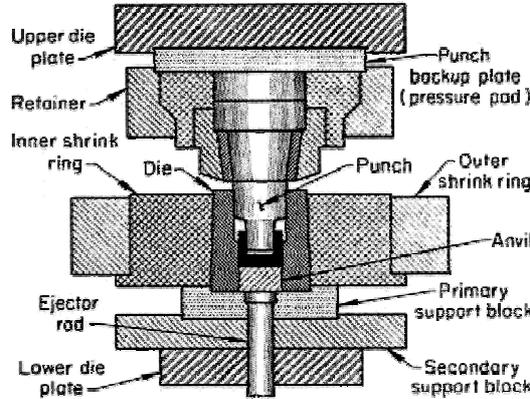

Figure 1. Tooling for backward extrusion of steel parts
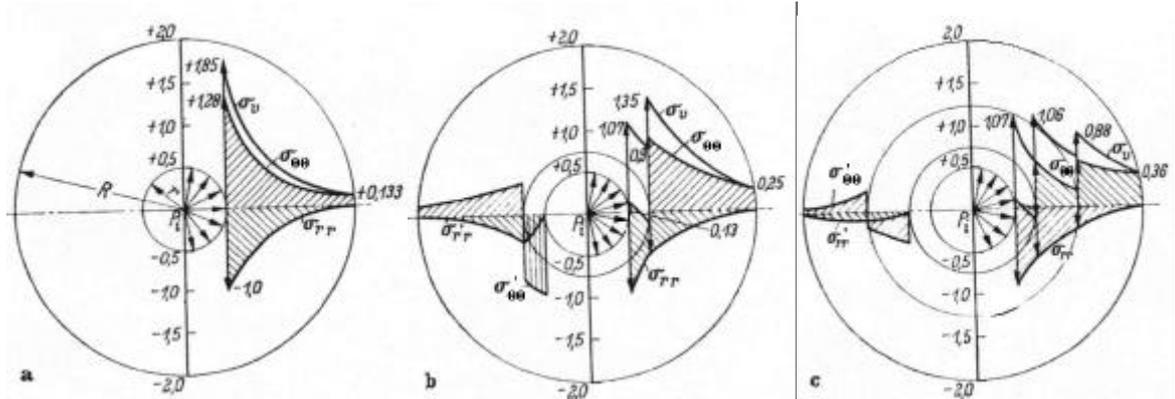
2   FORMULATION

Figure 2. (a,b,c) Stresses and loads on dies

Computations of shrink-fit assemblies are still based on the theory of an infinitely long hollow cylinder. The analytical solution can be derived from the Lame solution shown in *Eqs (1), (2)*.[1] In this equation the third principal stress is small and can be neglected, that is to say $s_{zz} = 0$. [10]

$$s_{rr,qq} = \frac{p_i \cdot r_1^2 - p_o \cdot r_2^2}{r_2^2 - r_1^2} \mp \frac{r_1^2 \cdot r_2^2}{r^2 \cdot (r_2^2 - r_1^2)} \cdot (p_i - p_o) \tag{1}$$

$$u_{rr} = \frac{r}{E \cdot (r_2^2 - r_1^2)} \left[(1 - 2n) \cdot (p_i \cdot r_1^2 - p_o \cdot r_2^2) + \frac{(1+n) \cdot r_1^2 \cdot r_2^2}{r^2} (p_i - p_o) \right] \tag{2}$$

σ_{rr}	: Radial Stress (Mpa)	p_i	: Inner Pressure (Mpa)
$\sigma_{\theta\theta}$	: Tangential Stress (Mpa)	p_o	: Outer Pressure (Mpa)
σ_v	: Equivalent Von Mises stress (Mpa)	u_{rr}	: Internal Displacement (mm)
r_1	: Inner Radius of Die (mm)	E	: Modulus of Elasticity (Mpa)
r_2	: Inner Radius of Inner Shrink Ring (mm)	ν	: Poisson Ratio
r_3	: Inner Radius of Outer Shrink Ring (mm)	z	: Absolute Interference Value
r_4	: Outer Radius of Outer Shrink Ring (mm)		

The effects of shrink ring is shown in Figure 2. For the case of Figure 2(a) there is no ring, there is one ring ring in the case of Figure 2(b) and there are two rings for the case of Figure 2(c). With a careful study of Figure 2 that the tensile stress is minimized for the case of two rings. Hardened tool steels have elastic limits up to σ_{Emax} = 2200 MPa. A simple die can, therefore, be subjected to a bursting pressure of at most: $p_{imax} \leq \sigma_{Emax}$. By using a double shrink ring the load can be even better distributed. The load peaks are here 1.07 p_i and 0.88 p_l, and evenly distributed over the whole cross section of the assembly *[10]*.

Figure 3. shows a die with two shrink fits. Since, the inner member of the tool is directly subjected to abrasion, the die can have smaller dimension and be replaceable. This method of arranging the tool assembly makes the tempering procedures simpler and also reduces notch stress weakness.
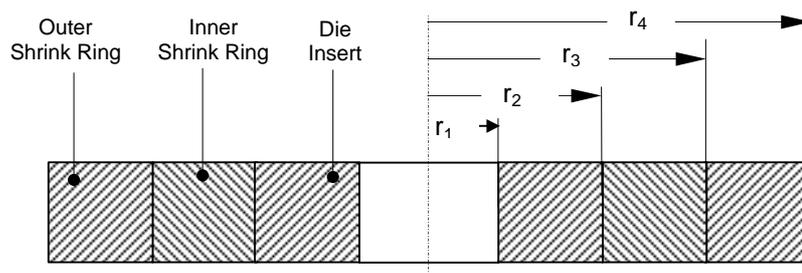

Figure 3. Double shrunk die for extrusion

3   MODELLING

In the present study, the finite element package ANSYS is used to predict the radial deformations, which have been occurred inner surface of the backward extrusion dies under maximum internal pressure. Two-dimensional eight-node isoparametric solid elements PLANE42 are employed to model all the components, namely, the backward extrusion dies. Contact interferences between the die and shrink fitted rings, are modeled by contact elements CONTAC 48 *[12]*

In this study, sample die radius is chosen in DIN standards *[DIN 5061 Tel 1]*. First, steel die block (W1 has 0.60 to 1.40 C), which is chosen in cold extrusion tools. It is meshed and loaded with maximum internal pressure for steel die, and then solved *[2]*. Radial stress, tangential stress and radial displacement are determined for dimensional variation of the die.
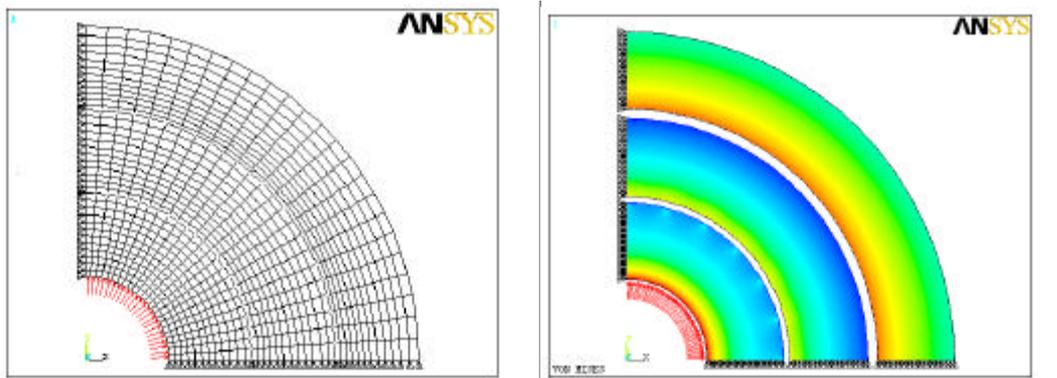

Figure 4. Finite element model and solution of the shrink-fitted die

The die block with the shrink fitted ring is modelled (press fit tolerances z=0.4%.d), and meshed again having max internal loading pressure for steel die with a shrink-fitted ring and solved. Radial stress, tangential stress and radial displacement are determined for dimensional variation of the die, and ring. Then the die block is modeled with two shrink fitted rings and meshed and loaded max internal pressure for this assemble and solved. Radial stress, tangential stress and radial displacement are determined for dimensional variation of the die and rings.

Finally, The radial deformations, u_{rr}, of inner surface of the die, are determined   then the best economic design is chosen.
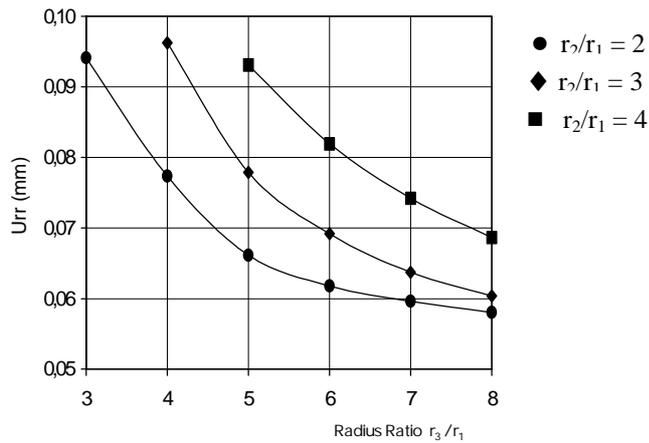
4   RESULTS AND DISCUSSION

Figure 5. Effect of Ratio r_3 / r_1 on internal displacement for shrink-fitted die assemblies
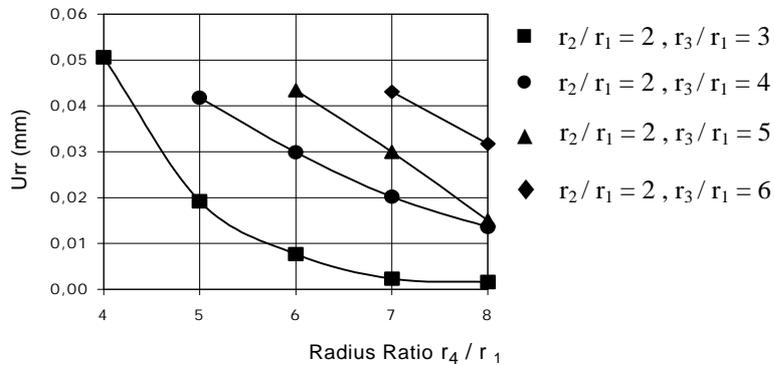

Figure 6. Effect of Ratio r_4 / r_1 on internal displacement for double shrink-fitted die assemblies
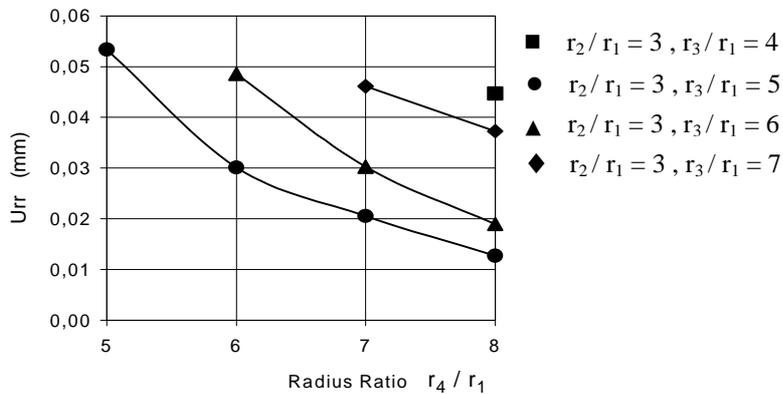

Figure 7. Effect of Ratio r_4 / r_1 on internal displacement for double shrink-fitted die assemblies
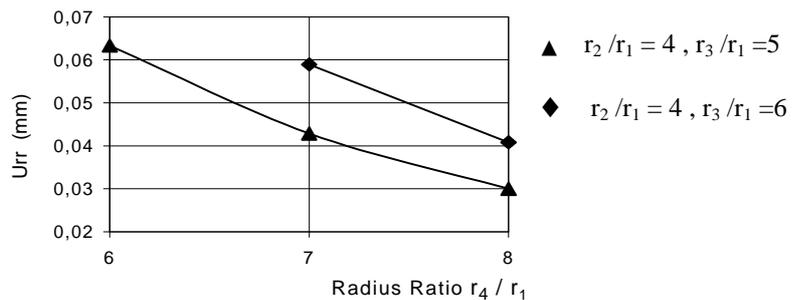

Figure 8. Effect of Ratio r_4 / r_1 on internal displacement for double shrink-fitted die assemblies

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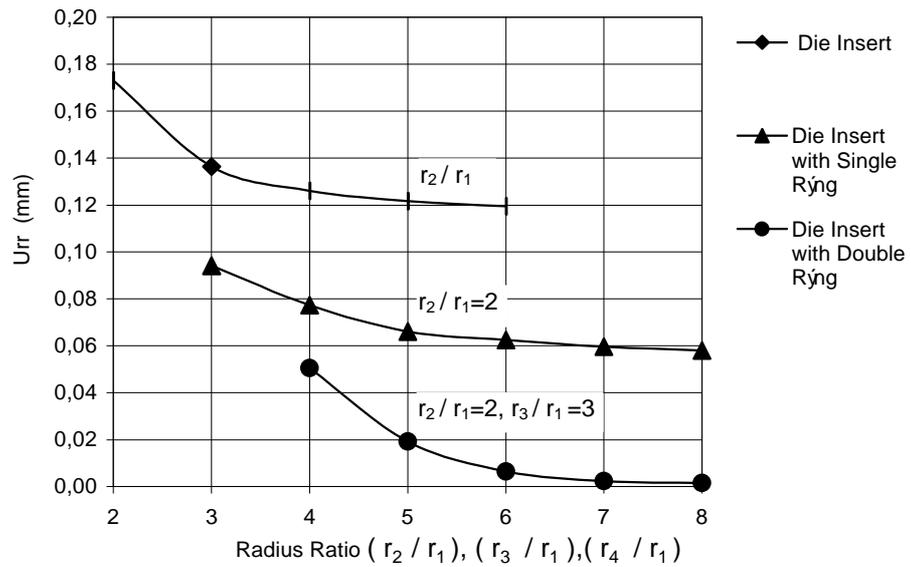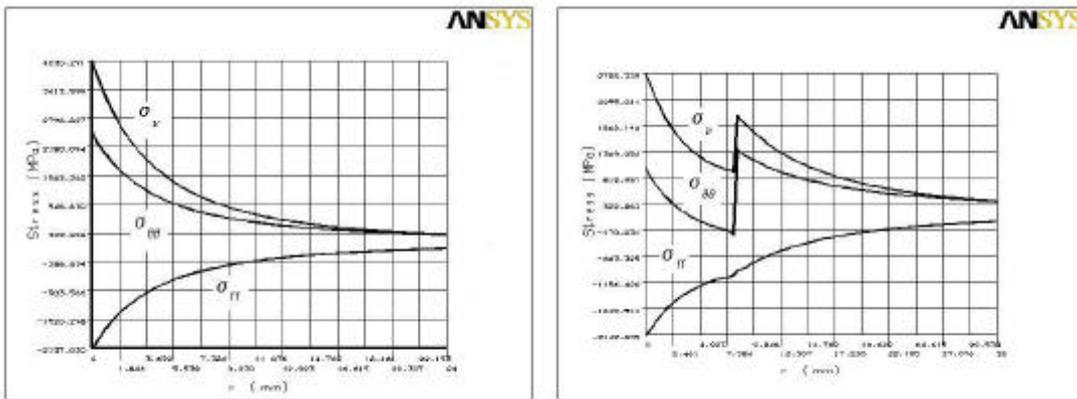**Figure 9.** Effect of number of shrink fit rings on internal displacement

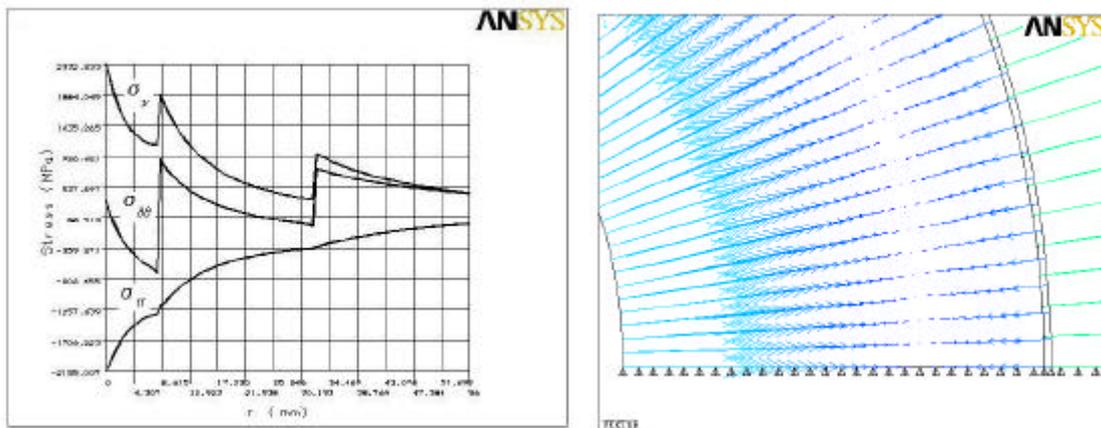(a)   (b)

Figure 10. *(a).* Stress distribution for the die ($r_2/r_1= 4$)
(b). Stress distribution for shrink-fitted die assemblies ($r_2/r_1=2,r_3/r_1=6$)

(a)   (b)

Figure 11. *(a).* Stress distribution for double shrink-fitted die assemblies ($r_2/r_1=2,r_3/r_1=5,r_4/r_1=8$)
(b). Vectorial stress distribution for double shrink-fitted die assemblies

Figure 5-11 show the variations in radial deformations U_{rr}, radial stress σ_{rr}, and tangential stress $\sigma_{\theta\theta}$, for various radius ratios of dies. By comparing the results it is clear that above the ratio $r_2/r_1=4$ the U_{rr} curve becomes asymptotic and hence an increas in r_2 is useless. For the single shrink design, with $r_2/r_1=2$, $r_3/r_1=5$ the U_{rr} curve receives an acceptable minimal for U_{rr}. For the $r_2/r_1=2$ and $r_3/r_1=3$ the U_{rr} curve becomes asymptotic beyond the ratio $r_4/r_1=7$ and for an increase in r_4 is meaningless.

5   CONCLUSIONS

The internal displacements are examined at the single shrink-fitted die and double shrink-fitted die under the effect of maximum internal pressure using Finite Element Software. The Ansys software is more suitable for contact problems solved by Finite Element Technique. The problem in this study has been modeled to achieve reasonable engineering accuracy with a low number of elements and iterations. A survey of the calculated results in this study shows an average accuracy within 1-2% of the theoretical solution. The results are in good agreement with the analytical solutions. This study shows the radial and tangential stresses and the resulting load on material for the case of a simple die for the radii ratio of $r_2/r_1 = 4$. The maximum values of the stresses and loads are at the inner surface of the die. Therefore, the material has to withstands the highest loads. *Figure* 5, 6, 7, and 8 shows, the results for smaller r_3/r_1 ratios for larger U_{rr} values. Tangential stress must be less than the elastic limits of the die steel, therefore r_3/r_1 ratios must be greater than 3 for shrink-fitted die. The shrink rings applies to the die a compressive prestress, which is opposite to the tangential stress. In case of shrink-fitted dies with two rings, smaller r_4/r_1 ratios result in larger U_{rr} values. Figure 9, shows the effects of number of shrink fitted rings on internal displacement.

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