Preform Map for Mild Steel Upsetting and Its Experimental Verification

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In upsetting process, an initial block of metal (billet) is compressed between two or more dies to produce a complex part. Geometry of the final product is strongly dependent on the shape of initial work piece as well as on the perform shapes at each of the subsequent forming stages. Design of the optimum preform for near net shape manufacturing is a crucial step in the designing of many upsetted products of mild steel. In this study, the same is realized by using profile map, which is generated using the results of FE simulations of varying geometrical and processing parameters. The map is further verified experimentally using a mild steel specimen. It is shown that preform designed on the basis of profile map results in near net shape manufacturing. Such map offers a powerful tool for near net shape upsetting.
***Keywords**: perform, finite element, upsetting, profile map, near net shape*

Introduction

Upsetting is an important metal forming operation. It is a class of bulk forming operation where large deformation is given to the material for shape and property modification. The major issue, which restricts imparting large deformation to the billet, is the bulging induced tensile stress, which later results in cracking. Bulge is also undesirable from near net shape manufacturing point of view, as it will require secondary processing like trimming. The friction between die and the work piece is mainly responsible for the formation of the bulge. To obtain the near net shape, preform design of the billets is a powerful solution.

Recently Roy et al. (1994) reported application of neural networks in interpolation of preform shapes in plane strain forgings. Ranatunga and Gunasekara (2006) presented preform design techniques based on the upper bound elemental technique with evidence of effective material usage and overall die life. Lee et al. (1997) reported application of an upper bound elemental technique in preform design for asymmetric forging. Liu et al. (1998) presented preform design method, which combines finite element method (FEM), and upper bound based reverse simulation technique and billet designed by this technique achieves a final forging with minimum flash. Ko et al. (1991) used neural networks and Taguchi method for preform design in multi-stage metal forming processes considering workability limited by ductile fracture. Srikanth and Zebaras (2000) presented a continuum sensitivity analysis approach for preform design in forging process. Chang and Bramley (2000) proposed reverse simulation approach clubbed with finite element analyses for preform design. Bramley (2001) reported a new method named as tetrahedral upper bound analysis, which enabled a more realistic flow simulation to be achieved. Antonio and Dourado (2002) introduced an inverse engineering formulation together with evolutionary search schemes for forging preform design. Shim (2003) presented optimal preform design for 3D free forgings using sensitivity approach and FEM. Tomov et al. (2004) reported on preform design of axisymmetric forging using FE software FORM – 2D. Ou (2004) reported finite element based approach, considering effects of die elastic deformation, thermal distortion and press elasticity to achieve net shape forging production for aero engine components. Poursina et al. (2004) proposed FEM and genetic algorithms (GA) based preform design procedure for axisymmetric forgings in view to achieve high quality products. Thiyagarajan and Grandhi (2005) presented 3-D preform shape optimization method for the forging process using the reduced basis technique. Repalle and Grandhi (2005) presented reliability based optimization method for preform shape design in the forging. Antonio et al. (2005) developed an inverse approach for preform design of forged components under minimal energy consumption using FEM and genetic algorithms. "Recently Park and Hwang (2007) reported preform design for precision forging of rib type aerospace components using finite element analysis.

It can be observed that most of above literatures address preform design as discrete problems considering one or few parameters. There is strong need of a generalized procedure of preform design considering varying geometrical and processing parameters. The proposed study is an attempt to fulfill this gap. The major objectives of this study are as follows:

(a) Development of methodology for preform design;
(b) Generation of preform map based on FE simulations; and
(c) Experimental validation of preform map on mild steel specimen.

Nomenclature

a = *middle diameter of undeformed billet, mm*
c = *top diameter of undeformed billet, mm*
a1 = *middle diameter of deformed billet, mm*
c1 = *top diameter of deformed billet, mm*
R = *a/c, diameter ratio of undeformed billet, dimensionless*

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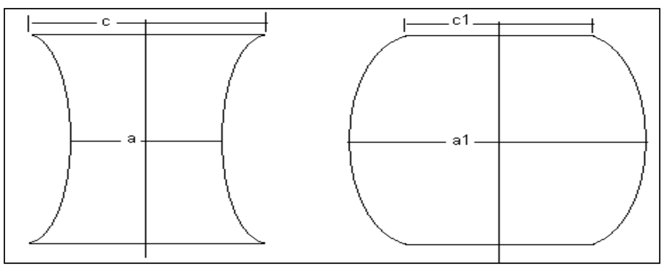
r = a1/c1 diameter ratio of deformed billet, dimensionless
σ = stress, Mpa
ε = strain, dimensionless
k = strength coefficient, Mpa
n = hardening exponent, dimensionless
μ = Coulomb's coefficient of friction, dimensionless

Methodology

In Fig. 1, undeformed and deformed billets are shown. Where top and middle diameters of these billets are c, a and c1, a1 respectively. Their diameter ratios can be expressed as R = a/c and r = a1/c1. It is obvious, for near net shape manufacturing r should be 1. The deformed profiles depend on geometrical and frictional conditions. Four sets of geometrical and three sets of frictional parameters, making total 12 cases, are considered in this study. Finite element simulations of these cases are carried out to obtain the deformation behavior. Based on these results, profile map is generated to predict desirable geometry for the given frictional conditions.



(a) Initial **(b) Deformed**

Figure 1: Initial and deformed shapes.

Mechanical Characterization

To obtain the material flow properties, as required for FE simulations, tensile test on the mild specimen is carried out. A mild steel specimen of gauge length 85 mm, prepared as per ASTM standard, is tested in an Instran Universal Testing Machine (UTM). The tested specimen is shown in Fig. 2. The summary of the results obtained from the tensile test is as follows:

(a) Ultimate Tensile Strength = 483 MPa
(b) Yield strength = 304 MPa
(c) Ultimate strain = 0.2
(d) Yield point strain = 0.002

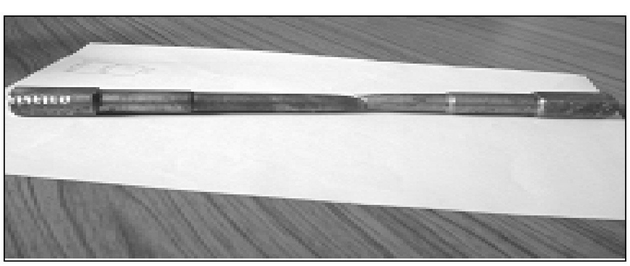


Figure 2: Tested tensile specimen.

From the tensile test data, engineering stress and strain are converted into their true counterparts. Material modeling has been carried out using the power law equation, Eq. (1) (Meyers and Chawla, 1997):

$$\sigma = k.\varepsilon^{n} \tag{1}$$

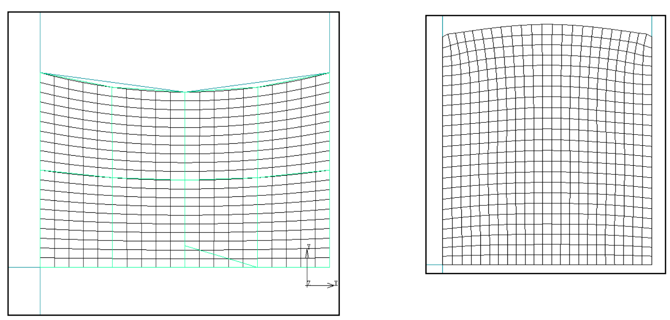
The value of k and n obtained from the tensile test results are 739.5 MPa and 0.104 respectively.

Geometrical, Material and Processing Parameters

Cylindrical billets of 38.3 mm top diameter and 40 mm height are used for simulation studies and generation of profile maps. The central diameters are considered as 30.64, 32.56, 34.47 and 36.38 mm. In this way center and top diameter ratios (R values) come out to be 0.8, 0.85, 0.9 and 0.95, respectively. Billets are considered to be made of mildsteel. Three values of Coulomb's friction μ, viz. 0.1, 0.15 and 0.2 are accounted in the simulation studies.

FE Simulation

Finite element analyses of the upsetting process are carried out using MSC Superform software (MSC, 2005). Curved profiles are modeled as arcs between top, middle and bottom diameters using ARC command of the software. Taking advantage of the symmetrical conditions, axisymmetric formulation is adopted. Four nodded elements are used for the FE modeling. There are 400 elements and 441 nodes in the model. Considering the variation in material, geometrical and frictional parameters, total 12 cases are simulated. Punch and die are modeled as rigid bodies. Bottom die is fixed whereas punch is movable which is given the displacement boundary condition. All the billets are identically deformed to final height of 31.9 mm viz. 20 % reduction in height. A typical FE and deformed models are shown in Fig. 3. Simulation results of the 12 cases are given in Table 1.



(a) Initial **(b) Final**

Figure 3: Finite element models: (a) initial, and (b) final.

Generation of Profile Map

To facilitate the design of preform for mild steel upsetting, profile map is generated based on FE simulations results. Twelve cases of varying parameters, given in Table 1, are considered for the same. Profile maps are the contour map of iso-deformed diameter ratio r value with respect to preform parameter R, and friction coefficient μ. For net shape manufacturing r values should be 1. The preform map for mild steel, generated using SURFER software (SURFER, 2002), is shown in Fig. 4. For the given friction and *R*, initial preform can be selected from the map. It can be observed that selection of initial parameters becomes very easy with such map. The flowchart adopted for the generation of profile map is given in Fig. 5.

Table 1: Simulation results.

S.No.	R	Friction coeff.	r	Plastic strain	Effe. Stress (MPa)	Max load (N)
1	0.8	0.1	0.864	0.3	273.4	6.90 x 10^5
2	0.8	0.15	0.88	0.317	248.6	7.18 x 10^5
3	0.8	0.2	0.895	0.344	314.5	7.35 x 10^5
4	0.85	0.1	0.906	0.281	183.9	7.62 x 10^5
5	0.85	0.15	0.923	0.305	263.8	7.80 x 10^5
6	0.85	0.2	0.939	0.345	326.6	7.97 x 10^5
7	0.9	0.1	0.949	0.271	184.2	8.24 x 10^5
8	0.9	0.15	0.968	0.315	275.4	8.42 x 10^5
9	0.9	0.2	0.985	0.363	333.7	8.58 x 10^5
10	0.95	0.1	0.995	0.288	195.5	8.84 x 10^5
11	0.95	0.15	1.014	0.34	283.4	9.01 x 10^5
12	0.95	0.2	1.031	0.388	335.3	9.16 x 10^5

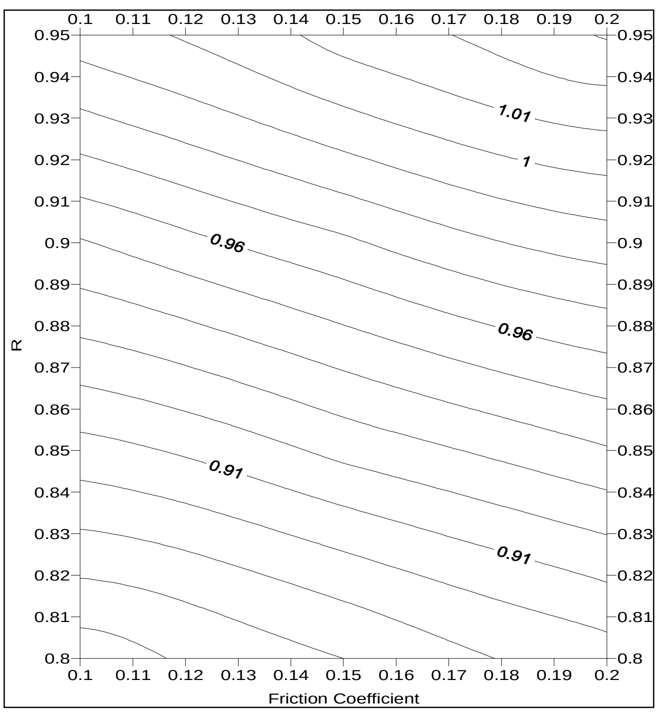


Figure 4: Profile map.

Mathematical Equations

Validation of the profile map is carried out on a real experiment using mild steel sample as described below:

(a) Friction Determination

The first step to use profile map is to determine friction between punch and billet. Friction is determined by using ring compression test. A mild steel ring of outer diameter 22.8 mm, inner diameter of 11.4 mm and height of 7.6 mm (OD:ID:H = 6:3:2), as shown in Fig. 6, is considered for the test. For 21% reduction in height, 5.4% reduction in internal diameter is observed. Using the calibration curve given in the standard text (Kalpakjian and Schmid, 2004), coefficient of friction μ (Coulomb) is obtained as 0.12.

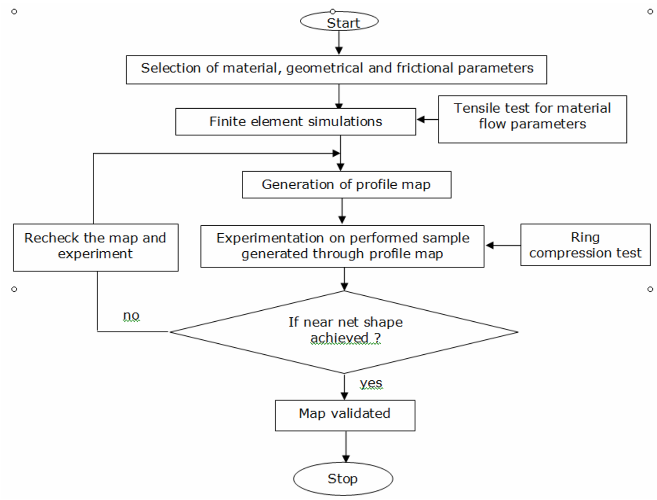


Figure 5: Flowchart of preform design.

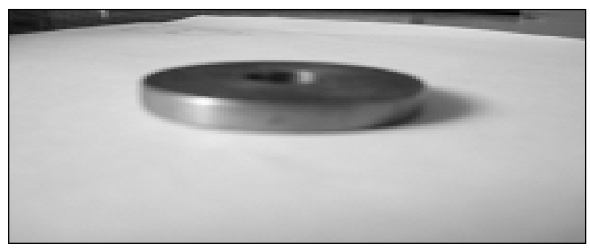


Figure 6: Tested ring specimen.

(b) Experimental Verification

The profile map generated using simulation results is verified through experiments on mild steel specimens. From the map, for friction coefficient of 0.12 and *r* as 1, *R* comes out to be 0.948. Based on that, a mild steel specimen of c = 38.3 mm, a = 36.3 and height of 40 mm having parabolic profile is prepared on a lathe machine. The preformed sample is shown in Fig.7. Billet upsetting is carried on compression testing machine of 1000 kN capacity. The height of the sample is reduced to 31.9 mm viz. by 20%. The final deformed specimen is shown in Fig. 7. Sample diameters at three locations, before and after deformation, are measured and given in Tab. 2. It can be observed that deformed sample is almost a cylinder, which is the required net shape.

Figure 7: Preformed and deformed billets

Table 2: Specimen geometries before and after test

Parameters	Initial	Final
Diameter at top (mm)	38.3	41.19
Diameter at middle (mm)	36.3	41.19
Height of the billet (mm)	39.9	31.90

Conclusion

In this study, preform map for net shape upsetting of mild steel specimens is developed. These are based on elaborate finite element studies considering various geometrical (R) and processing (μ) parameters. Thus, developed map is verified experimentally using a mild steel specimen. It is found that initial preform designed on the basis of profile map results in near net shape. The proposed approach will be helpful to the design engineers in selection of the appropriate geometrical and processing parameters for upsetting process design.

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