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Effects of Process Parameters on Copper Powder Compaction Process Using Multi-Particle Finite Element Method

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Abstract: Powder metallurgy (PM) has been widely used in several industries; especially automotive and aerospace industries and powder metallurgy products grow up every year. The mechanical properties of the final product that is obtained by cold compaction and sintering in powder metallurgy are closely related to the final relative density of the process. The distribution of the relative density in the die is affected by parameters such as compaction velocity, friction coefficient and temperature. Moreover, most of the numerical studies utilizing finite element approaches treat the examined environment as a continuous media with uniformly homogeneous porosity whereas Multi-Particle Finite Element Method (MPFEM) treats every particles as an individual body. In MPFEM, each of the particles can be defined as an elastic- plastic deformable body, so the interactions of the particles with each other and the die wall can be investigated. In this study, each particle was modelled and analyzed as individual deformable body with 3D tetrahedral elements by using MPFEM approach. This study, therefore, was performed to investigate the effects of different temperatures and compaction velocities on stress distribution and deformations of copper powders of 200 μm-diameter in compaction process. Furthermore, 3-D MPFEM model utilized von Mises material model and constant coefficient of friction of μ=0.05. In addition to MPFEM approach, continuum modelling approach was also performed for comparison purposes.
Keywords: Multi-Particle Finite Element (MPFEM), Powder Metallurgy, Compaction Process, Compaction Velocity

1. Introduction

Optimization of the mass production parameters of Powder Metallurgy (PM) products, which are continuously increasing in industrial use, is very important in terms of reducing the production costs. Experimental determination of compaction process parameters is more costly than numerical methods.

Numerical methods are more efficient in terms of cost reduction, fast results, and close follow-up of parameters. Discrete Element Method (DEM), Finite Element Method (FEM) or Smoothed Particle Hydrodynamics (SPH) are some of the proper numerical methods to analyze compaction processes [1, 2].

Being an established model for the analysis of rigid particles, DEM is able to make elastic plastic analyses integrated with FEM as a result of the developments in time [3]. Mazor et al. [4] investigated roll compaction process with a combined Discrete and Finite Element method and figures out rolling process parameters.

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However, the FEM shows more successful results. FEM analyses are also examined in two groups of approaches; continuum media approaches [5] and multi particle finite element method (MPFEM) [6]. The area to be investigated in the continuum approach is considered to be a solid body with a certain relative density. However, in MPFEM, each particle is defined as an elastic plastic independent body, and interactions between the particles can be examined [7]. Stresses, deformation, friction coefficients, particle interactions can be studied with more accuracy by the MPFEM approach [8].

The final relative density, punching force, particle distribution and pressing velocity are important in modelling the of compaction process. Yan et al. [9] studied compaction process of titanium powders to obtain process characterization. Moreover, Yan et al [10], investigated different particle size in order to get the size effect on compaction process.

In this study, copper powders in a diameter of 200 microns were compacted with temperature parameter of 20°C, 270°C, 400°C and 541°C in order to investigate temperature effect at 0.4mm/s, 0.8mm/s, 1.6mm/s, 4mm/s and 8mm/s compaction velocities with a proper material model. Work hardening elasto-plastic von Mises material model utilized to model copper in powder compaction process, similar to the previous studies given in literature [7, 11, 13]. Numerical results obtained from analyses were evaluated in terms of stress and particle distribution.

2. Numerical Studies

2.1. Finite Element Model

The geometrical details of numerical model is shown in Figure 1. The teeth angle of the die is 45° while ratio of the tooth width to its height is 0.5. The geometry of numerical model was taken from the study of Cora et al. [14]. 130 spherical particles with 200µm diameter was filled in the die. In aim to establish a realistic model, particles filled under effect of gravity using SolidWorks software (Solidworks Corp., Waltham, MA, USA). The pre-model meshed by 93000 tetrahedral elements with the capability of Patran software (MSC Software Corp., Santa Ana, CA, USA). Later on the model was imported into commercial Finite Element Analyses (FEA) package MSC Marc (MSC Software Corp., Santa Ana, CA, USA) and numerical analyses of compaction process was then performed by MSC Marc Mentat Solver.

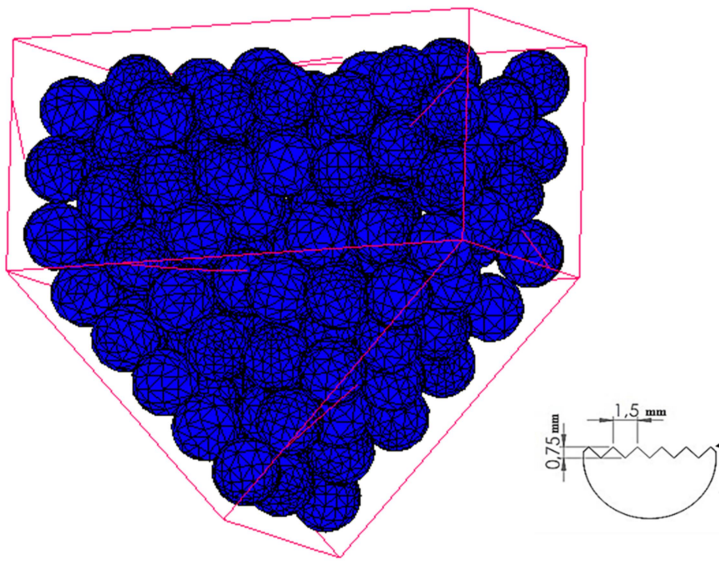


Figure 1 Numerical model (MPFM) of compaction process.

2.2. Material Model

In all FE analyses, von-Mises yield function along with power law was utilized in aim to represent work hardening issue [12]. The constitutive equation of von-Mises yield function is given in Eq. (1)

$$\sigma_Y = A(\varepsilon_0 + \bar{\varepsilon})^m + B\dot{\bar{\varepsilon}}^n \quad (1)$$

where σ_y is the yield stress, ε_o is initial yield strain, $\bar{\varepsilon}$ is equivalent strain, $\dot{\bar{\varepsilon}}$ is equivalent strain rate. The other material parameters were tabulated in Table 1. Parameter B takes very small value for 20°C and 270°C analyses so that it was ignored [15]. The parameters were taken from Güner at al. [11] or calculated by the similar method given in the mentioned reference where it is necessary.

Table 1. Material parameters used in numerical analyses

Material Parameter	20°C	270°C	400°C	541°C
A	451.6 (MPa)	296.7 (MPa)	64.56 (MPa)	42.12 (MPa)
B	0	0	202.16 (MPa)	151.91 (MPa)
m	0.324	0.3655	0.167	0.149
n	0	0	0.0079	0.0858
E	110 (GPa)	99.3 (GPa)	62 (GPa)	38.2 (GPa)
v	0.35	0.35	0.35	0.35
σ_0	28.8 (MPa)	10.49 (MPa)	16.3 (MPa)	12.79 (MPa)

2.3. Friction Model

Amonton-Coulomb friction model which states friction stress as a portion of normal stress used for numerical analyses. A constant coefficient of friction that is shown by μ_c in Eq.2 expresses the proportionality of normal and friction stresses. $\boldsymbol{\tau}$ and $\boldsymbol{\sigma_n}$ stand for the shear and the normal stresses in Eq.2, respectively. A value of 0.05 was applied as a constant coefficient of friction to all MPFEM analyses [11].

$$\tau = \mu_c.\sigma_n \quad (2)$$

3. Results and Discussion

The numerical analyses was performed by Intel I7 2.20 GHz microprocessor along with 6 GB of RAM equipped PC. The mean analysis time was 43 hours and the study was completed with 20 successful analyses. Compaction processes under 0.4 mm/s, 0.8 mm/s, 1.6 mm/s, 4 mm/s and 8 mm/s punch velocities was analyzed at temperatures of 20°C, 270°C, 400°C and 541°C. 130 spherical copper powders were compacted in a die volume of 1.11 mm^3. Relative density (RD) which is the ratio of total particle volume to die volume changed from 49% to 79% throughout the compaction process.

Figure 2 shows the equivalent von Mises stress distribution of MPFEM analyses of copper powder compaction at 541°C. Maximum equivalent stress at 0.4 mm/s punch velocity is 205 MPa while it increases to 247 MPa at 8 mm/s punch velocity. The particles showed more homogenous stress distribution for the maximum value at 0.4 mm/s analyses. On the other hand, analyses at 8 mm/s, particles had less deformed shapes around the discontinuities of the die. The particles those are contacting with the punch and discontinuities of the die had more deformed shape although the stresses were not differ from the other particles. In their study of cold powder compaction by using the discrete element method Jerier et al [16] expressed that stress showed sudden increase after 80%RD

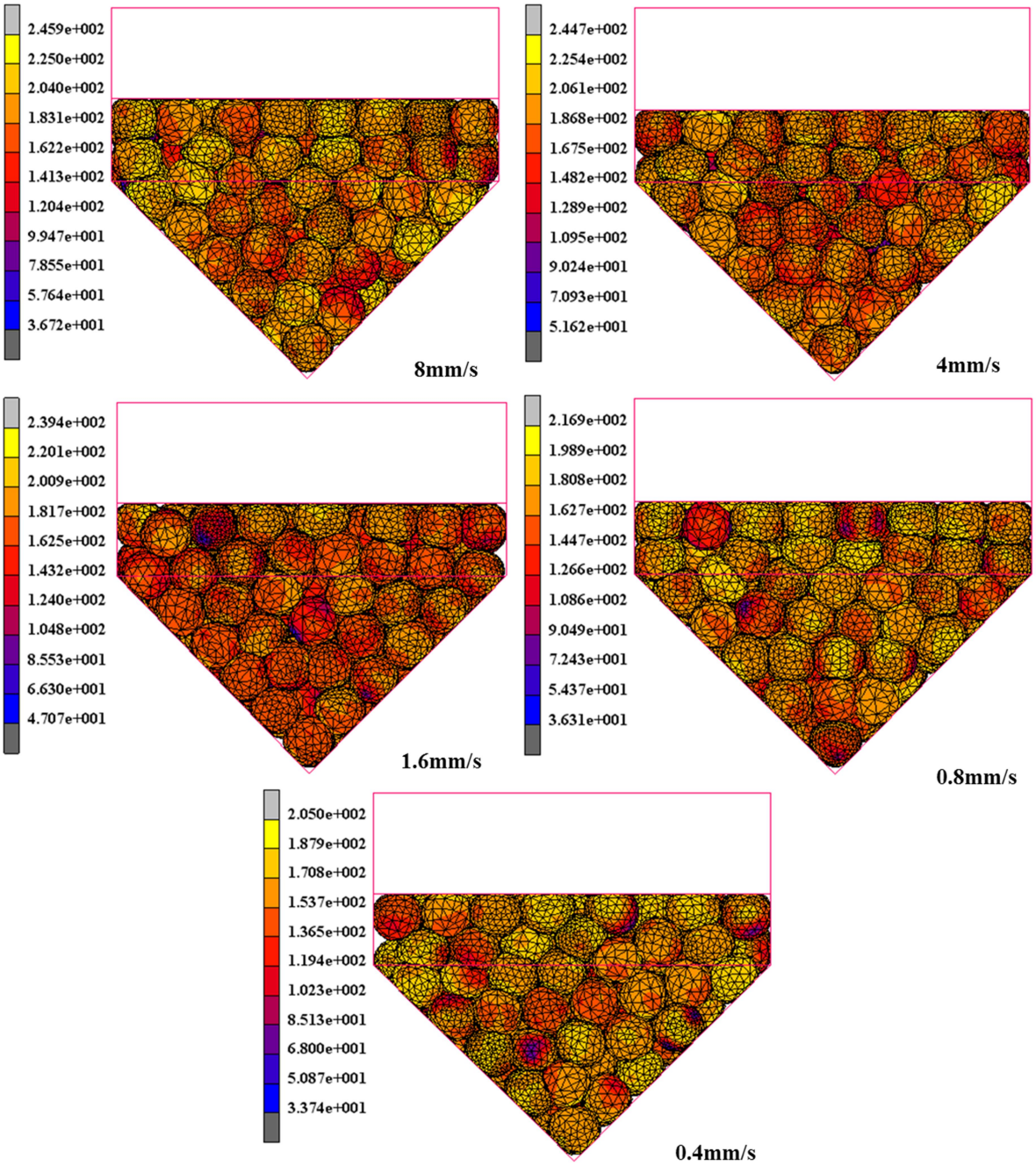


Figure 2 Equivalent stress distribution in MPFEM analyses at 541°C

Figure 3 shows equivalent stress distribution of MPFEM analyses at 270°C. In the analyses of 0.4 mm/s, the particles had more homogenous stress and deformation distribution. It can be seen that the particles were generally in blue or red in 0.4mm/s analyses. The particles especially contacting with the punch were exposed to excessive stresses on which maximum value of analyses were more apparent on them at punch velocities of 4 mm/s and 8 mm/s. In 8 mm/s punch velocity, the particles did not have enough time to rearrange and fill the gaps of die homogeneously.

The MPFEM analyses of copper powder compaction at 20°C and 400°C had similar stress distributions. The maximum equivalent von-Mises stress values of those analyses were given in Table 2. In all analyses maximum stress values increase in parallel with punch velocity increase. Also maximum value of equivalent von Mises decrease by temperature increase due to yield stress.

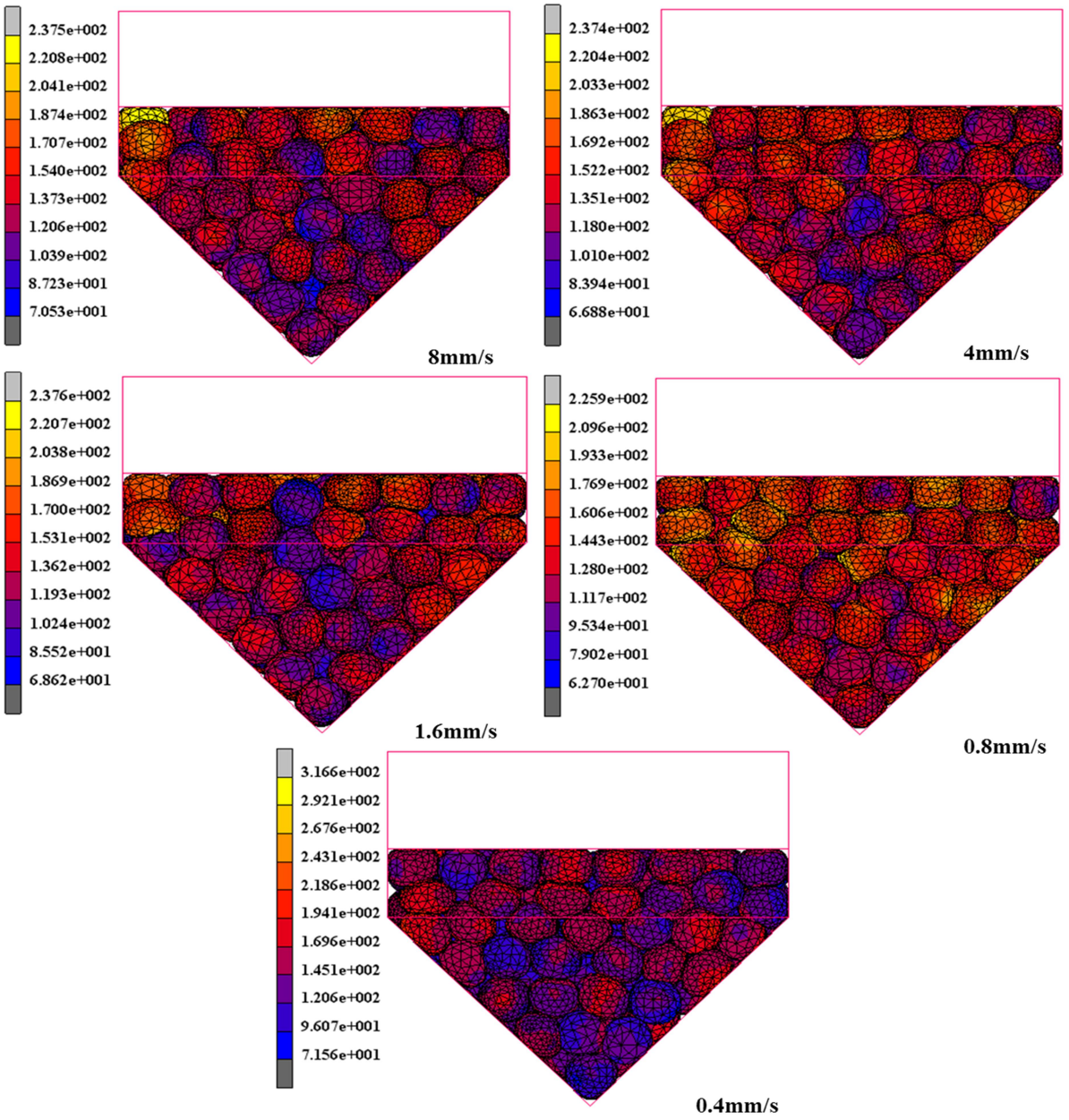


Figure 3 Equivalent stress distribution in MPFEM analyses at 270°C

Table 2. Maximum Equivalent von Mises stress values of MPFEM analyses

Max. Equivalent von Mises Stress (MPa)				
	20°C	270°C	400°C	541°C
0.4mm/s	366	316	282	205
0.8mm/s	354	225	283	216
1.6mm/s	402	237	291	239
4mm/s	343	237	315	244
8mm/s	372	237	314	247

Figure 4 shows the punch stress change via relative density. Except 1.6 mm/s analyses, punch stress arises after 61% RD cause of particle rearrangement. Particles were being rearranging until RD reached 61% and inter particle actions became more stable after this value of RD. The punch stress for 20°C MPFEM analyses varies between 160 MPa-180 MPa. The parabolic trend line of punch stress after 61% RD shows good agreement with the study of Jerier et al [16].

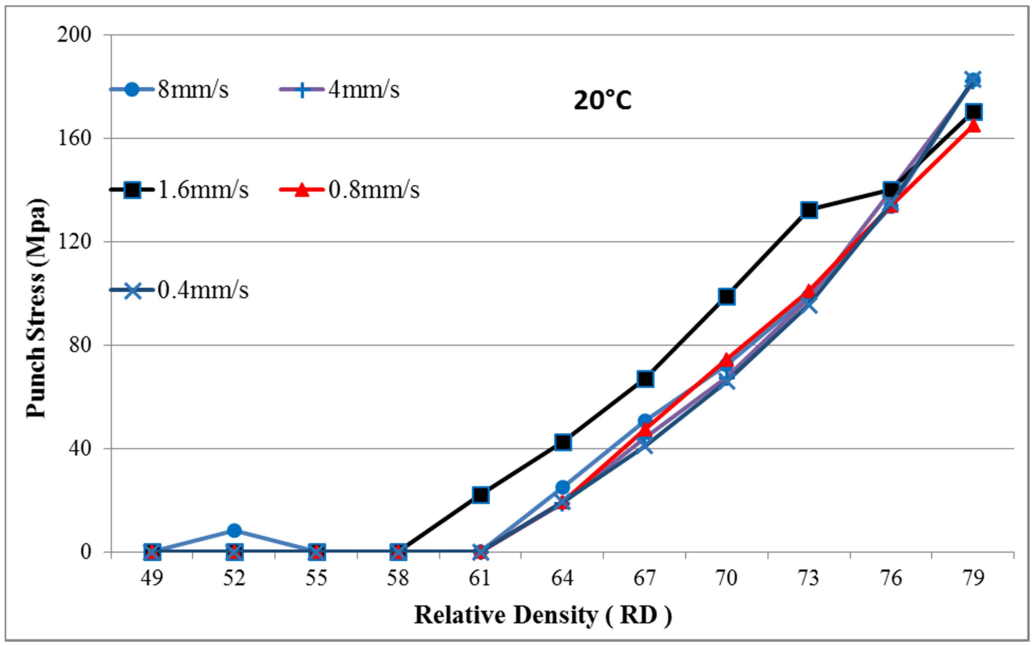


Figure 4 Punch stress of MPFEM analyses at 20°C

The punch stresses at the end of all MPFEM analyses are given in Figure 5. Although the stresses at the punch velocities of 8 mm/-s and 0.4 mm/s are close to each other, a sudden change in the stresses around the speed of 1.6mm/s has been achieved in Figure 5. The punch stresses differ from 110 MPa to 180 MPa due to varying temperature and punch velocity. Majzoobi and Jannesari [17] investigated copper powder compaction process experimentally in order to get cap material model parameters and figured out a punch stress varying between 120-160 MPa showing a good agreement with the present study.

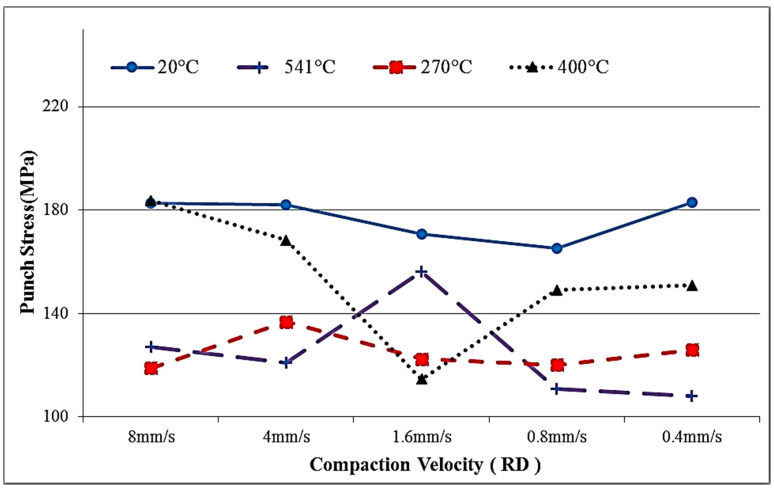


Figure 5 Punch stresses of all MPFEM analyses via punch velocity

4. Conclusion

MPFEM analyses of copper powder compaction process at 0.4 mm/s, 0.8 mm/s, 1.6 mm/s, 4 mm/s and 8 mm/s has performed in 20°C, 270°C, 400°C and 541°C in order to investigate effects of punch velocity and temperature. Within the limitation of study, followings are obtained:

1- The punch stresses of all MPFEM analyses varied from 100MPa-180MPa with a good agreement in the literature.

2- The punch stress showed sudden changes around 1.6 mm/s punch velocity so that this value of velocity can be named as a critical value.

3- If the punch velocity is low, particles can be rearrange in die so that a homogenous stress distribution can be observed in die.

4- High punch velocities can cause excessive shape deformation on particle especially around the punch and the zones where die has geometrical discontinuities.

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