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Computational Mechanics Laboratory (CompMechLab), ANSYS Center of Excellence
St.Petersburg State Polytechnical University, WWW.FEA.RU, WWW.ANSYS.SPb.RU

Non-linear Finite Element Modeling of the Titanium Briquettes Hot Extrusion Process

Alexey I. Borovkov

Denis V. Shevchenko

Computational Mechanics Laboratory, St.Petersburg State Technical University, Russia

Abstract

In this paper the mathematical model is developed to perform mathematical simulation of the hot extrusion process. The model makes it possible to observe the influence of various system parameters on the extrusion process. All researches were carried out with the use of the ANSYS 5.6 RFS FE-software system. During the research the modeling and analysis of various events that can be observed (material dead zone appearing, capsule crimping, capsule damage etc.) was successfully carried out. The mathematical model was created on the basis of contact thermo-mechanics relations with physical and geometrical non-linearities.

Introduction

The present paper considers one of the methods of metal hot treatment relating to powder metallurgy. Among known and various methods of metal treatment, powder metallurgy occupies a distinctive place, successfully competing with casting, machining and other methods, adding and substituting them.

Using powder metallurgy methods, it is possible to substantially diminish scrap, appearing in application of other metal hot treatment methods. It should be also mentioned that application of powder metallurgy methods especially expedient economically for rare and expensive materials, e.g. for titanium [3].

The traditional technology of obtaining titanium rods and wire is based on reprocessing large, massive ingots. Therewith, multiple deforming with intermediate annealing and etching is required to be fulfilled. Considerable amount of metal is being lost, forming irreversible production waste, what substantially increases titanium product costs.

In this paper we consider one of the modern and promising methods of powder metallurgy – hot pressing (extrusion) that allows obtaining products with mechanical properties and compactness close to those of conventional industrial titanium and does not lead to high loss of material [4].

The present work comprises finite element (FE) modeling and a research of the hot extrusion process. With the use of the ANSYS FE software, it was developed and realized a principally new mathematical model for numerical simulation of the hot extrusion technological process [2]. The developed model enables us to investigate various phenomena, watched in practice, emerging in the deforming process; expose and research the effect of various design and technological factors on the process; optimize the most important parameters of the construction: curvature radius of a pressing die, size of a gap between a blank and a pressing rig etc.

Procedure and Analysis

The general view of the investigated construction is shown in Fig 1 where A1 – steel capsule, A2 – titanium briquette, A3 – press container, A4 – pressing die. A steel capsule A1 combined with a titanium briquette A2 form a deformed block, or encapsulated titanium briquette.

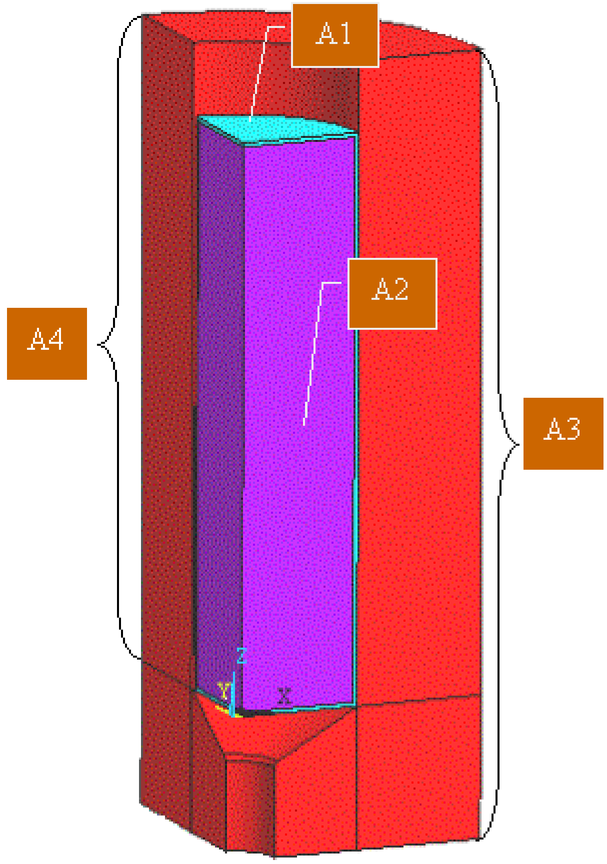

Figure 1 - General View

Let us describe properties and material models used in the analysis:

Steel capsule A1 is characterized by the following physical and mechanical properties:

modulus of elasticity $E = 158$ GPa

Poisson's ratio $\nu = 0.45$

Yield strength $\sigma_{0.2} = 108$ MPa

Tangential modulus $E^{tan} = 7$ GPa

Linear coefficient of thermal expansion $\alpha = 1.459 \cdot 10^{-5}$ K^{-1}.

For description of strains originating in a capsule was chosen the model for plastic material with Bilinear Kinematic Hardening [1].

For analyzing a behavior of titanium briquette A2 the following physical and mechanical properties were taken into account:

modulus of elasticity $E = 79.2$ GPa

Poisson's ratio $\nu = 0.45$

yield strength $\sigma_{0.2} = 9.8$ MPa

tangential modulus $E^{tan} = 0$

linear coefficient of thermal expansion $\alpha = 1.05 \cdot 10^{-5}\ K^{-1}$.

For description of strains originating in a titanium briquette was chosen the model for ideal plastic material (Bilinear Kinematic Hardening, $E^{tan} = 0$).

Steel capsule A1 and titanium chips were assumed to be at 950^{0}C.

Pressing-die A3 was manufactured from steel with the following elastic characteristics:

modulus of elasticity $E = 210$ GPa

Poisson's ratio $\nu = 0.28$

In numerical simulation it was assumed that a pressing die deforms only elastically, its temperature being 300C°.

Owing to the axial symmetry of the analyzed construction and external action, the axisymmetrical statement of the problem is being considered.

Vertical displacement or normal pressure is applied to the deformed block. Accordingly, possibility of multiple contact interaction between a titanium briquette and a steel capsule, as well as between lateral and bottom parts of a capsule and the inner surface of pressing rig was supposed to take place. The possibility of the slipping and "ungluing" of a titanium briquette in relation to a steel capsule as well as of the whole deformed block in relation to a pressing die was taken into account. It was investigation the effect of friction coefficient μ varied within the range 0 … 0.5 on the extrusion process. Contact interactions were described with the use of Coulomb's law.

Various construction variants differing by geometrical characteristics of a titanium briquette, a capsule and a press-container were investigated in computation models.

Figure 2 demonstrates the built axisymmetrical ANSYS FE-model compiled of 8-noded quadratic elements SOLID 82. The FE-model contains 647 elements and 836 nodes. Contact interaction between a titanium briquette and a steel capsule as well as between lateral and bottom parts of a capsule and the inner surface of pressing rig was simulated with the use of elements CONTACT169 and TARGET172.

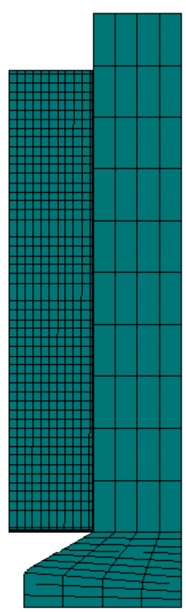

Figure 2 - FE Model

Analysis Results

The software system ANSYS made it possible to research the following:

- the initial stage of titanium briquette extrusion process;

- peculiarities of technological problems of deformed solids mechanics connected with unknown contact areas between deformed medium and pressing rig. The possibility of the slipping and "ungluing" of a titanium briquette and a steel capsule as well as between lateral and bottom parts of a capsule and the inner surface of pressing rig was supposed to take place. (Figure 3).

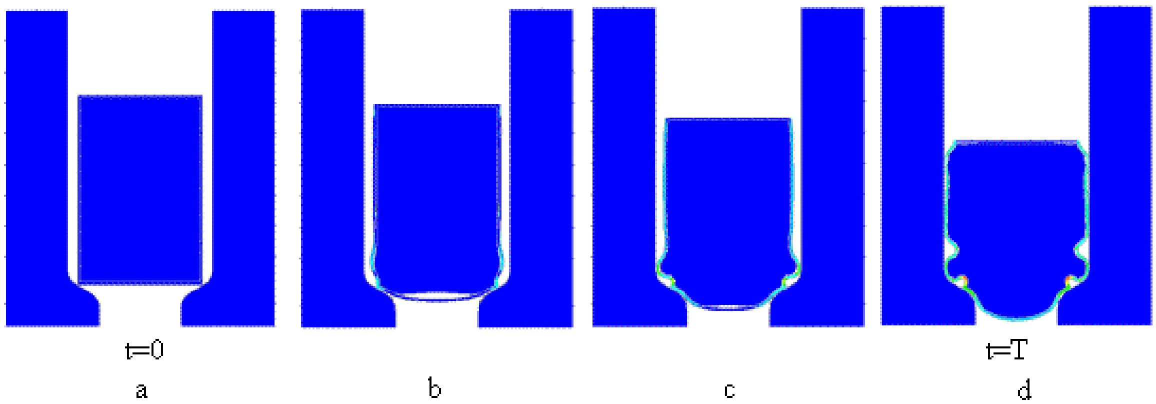

Figure 3 - Contact Interaction Peculiarities

- material tightening in the area near the axis of symmetry and the phenomenon of pressing-pipe formation – the phenomena which may be watched in real processes of extrusion (Figure 4). Figure 4 demonstrates the results of the modeling of pressing-pipe emergence, its growth and final formation. The initial position of the deformed block (encapsulated titanium briquette) is presented in Figure 4*a* (**t**=0). (**t** – is relative time instant accepted as a corresponding part of a full cycle **T** of pressing-pipe formation). Figures 4 *b-e* illustrate initial stages of pressing-pipe emergence correspondingly in the instances **t**=0.143**T**, 0.286**T**, 0.429**T**, 0.572**T**, Figures 4 *f-h* – growth and final formation of a pressing-pipe (for instances **t**=0.715**T**, 0.858**T** and 1**T**), as well as the phenomenon of block sticking in a pressing-die eyelet;

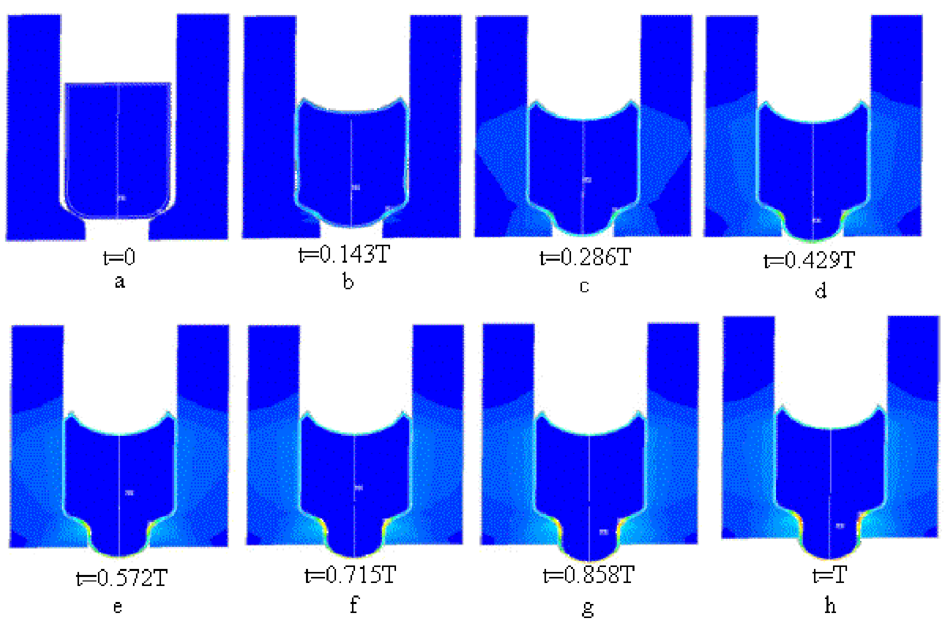

Figure 4 - Pressing-pipe Formation

- zones of stagnation, sliding, sticking–detaching, crimping, which are typical to technological problems with multiple contact zones.

The results of flute-formation modeling are illustrated in Figure 5, where on can see the initial stage of the investigated system (**t**=0) (**t** – is relative time instant taken as a corresponding part of a full cycle **T** of flute formation under pressure Figure 5 *a*, emergence and evolution of three flutes at the time instances **t**=0.2**T**, 0.4**T**, 0.6**T**, 0.8**T**, **T** shown in Figures 5 *b-f* correspondingly.

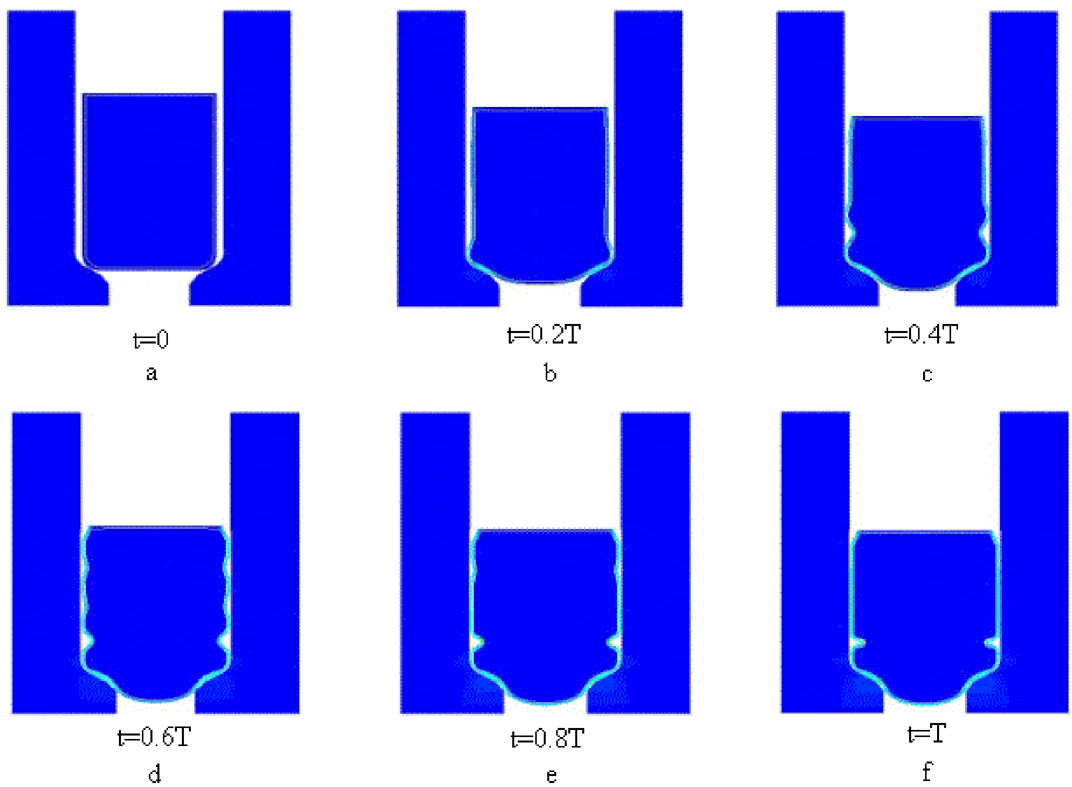

Figure 5 - Flute-formation

It is important to notice that the two upper flutes disappear in time, but the lower one even increases and more and more penetrates into titanium briquette body, increasing in its depth. This may cause serious defect ness of extruded rods and necessity of deep rough machining or even their rejection.

The results of the real experiment carried out in a drawing press at the "Krasny Vyborzhets" Plant, Ltd., and the virtual experiment performed with the use of computer modeling based on the ANSYS – software system are demonstrated in Figure 6. As we can see, there is sufficient similarity of received pictures giving evidence of validity of the software used for description of initial stages of the extrusion process.

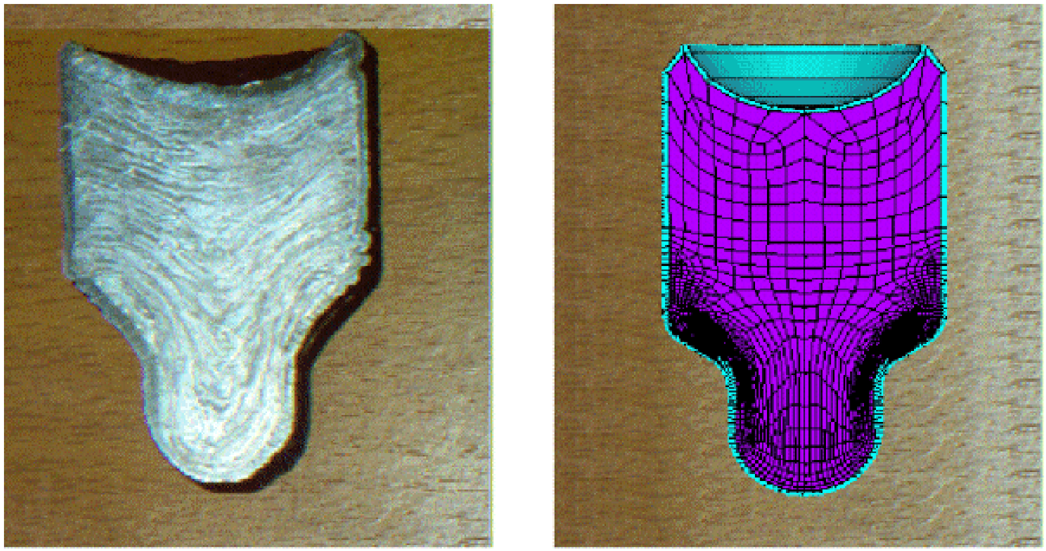

Figure 6 - Comparison of Experiment and FE Simulation

Conclusion

With the use of ANSYS FE-analysis software system:

- there were studied and researched peculiarities of technological problems of deformed solids mechanics connected with unknown contact areas between deformed medium (encapsulated titanium powder briquette) and pressing rig;

- there were investigated different phenomena emerging at the initial stage of encapsulated titanium briquette extrusion, including:

- material tightening in the area in the vicinity of the axis of symmetry and the phenomenon of pressing-pipe formation;

- emergence, formation and evolution of "stagnation", sliding and sticking-detaching zones;

- steel capsule crimping in the area of its contact with a press-container and flutes evolution during the process of deforming. It was stated possibility both of their further growth with penetration into encapsulated titanium briquette body and their partial disappearing.

It was investigated the effect of geometrical parameters of a press-container and an encapsulated titanium briquette on the processes occurring during deforming.

It was achieved good conformity of real and virtual pictures of the initial extrusion stage obtained correspondingly by the experiment carried out on the industrial press at "Krasny Vyborzhets" Plant, Ltd. and by computer modeling of the hot extrusion process that proves validity of the utilized mathematical model for this stage of hot deforming.

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