БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ • BULGARIAN ACADEMY OF SCIENCES

ПРОБЛЕМИ НА ТЕХНИЧЕСКАТА КИБЕРНЕТИКА И РОБОТИКАТА, **61**
PROBLEMS OF ENGINEERING CYBERNETICS AND ROBOTICS, **61**

София • 2009 • Sofia

Modeling of Grain Deformation in the Process of Cold Plastic Deformation

Todor Penchev, Dimitar Karastoyanov

Central Laboratory of Mechatronics and Instrumentation, 1113 Sofia

1. Introduction

The Finite Elements Method (FEM) is used successfully to study processes occurring in metals and metal alloys at micro-level – the appearance and development of cracks and other defects [1-3]; to study the changes of microstructure in plastic deformation [4-8]; modeling the structure and subsequent recrystallization [9, 10]. In these studies the distorted environment is presented in two ways: as an ongoing continuum, at mechanical approach [1-3, 9] or as metallographic structure of several grains, the shape of which is randomly selected [4, 7]. The changes in crystallographic texture is modeled by FEM in [5, 11] in cold drawing of wire of a large number of grains using a supercomputer with over 6000 processors working in parallel.

In order to use in industry and research the deformation modeling of grains of a real metal structure in the process of cold plastic deformation, an approach should be used in which the work with a real structure and modeling is possible with the available computer configurations working with FEM. Such an approach is developed for the case of cold deformation of a single metal structure in department "Material science and technology of materials" at Technical University of Sofia [12, 13] Ansys software is used in deformation of the initial slug deflection up to 25% . In real processes usually two-phase metal alloys are used to the degree of deformation up to 60%, for which further development of the idea is necessary, using appropriate software for FEM. This original program module integrated into the specialized FEM system MARC was developed by a team at the Institute of Mechanics, Bulgarian Academy of Sciences. A number of studies were conducted, of the processes of cold and hot plastic deformation at large degrees of deformation [14-19].

The actuality of the problem is that conditions for real work are created, while working on virtual simulation models of processes in plastic deformation. Virtual models in this area are the newest directions for research related to industrial applications [20, 21]. Thus one can obtain a real picture of the deformation of grains in various areas of a deformed body, which is a prerequisite to predict the structure and properties of the products after cold deformation.

Already in the 80's of last century, mathematical models and computer programs have been developed for modeling the processes of static recrystallization after cold plastic deformation. Since then these models are continuously improved [9, 10, 14, 15]. In all the cases, however, these models work with a real initial structure obtained from the observations of metallographic micro sections of deformed bodies. Developing of this project will create conditions for use in the models of recrystallization virtual real structure, i.e., conditions for the development of integrated virtual process including the process of cold deformation and subsequent recrystallization

2. Scientific problems

The research tasks to be solved are in the field of methodology of research, mathematical modeling of real structure in cold plastic deformation, the development of original software and testing the accuracy of modeling. In particular we see the following tasks in these areas:

- improving the methodology developed in IMeh-BAS, modeling with FEM of monophase real structure (pure metal) in cold plastic deformation to its application in deformation levels up to 60%;
- develop a methodology for modeling by FEM the deformation of grains in a real two-phase structure with cold plastic deformation;
- creating a mathematical model for the relationship between the data obtained in the simulation model with FEM of the macro- deformation of a sample, with micro-deformation of the grains of the real structure of a similar real model, with a mono-phase structure;
- creating a mathematical model for the relationship between the data obtained in the simulation model with FEM of the macro-deformation of a sample, with micro-deformation of the grains of the real structure of a similar real sample, with a two-phase structure;
- development of original software for realization of a structure in the process of cold plastic deformation;
- development of original software for realization of a mathematical model for deformation of the grains of real two-phase structure in the process of cold plastic deformation;
- develop a methodology for experimental testing the accuracy of modeling deformation of grains of mono- and two-phase metal structures;

• conduct comparative experimental studies to determine the accuracy of modeling of deformation of grains of mono- and two-phase metal structures.

3. Methodology

The methodology of deformation modeling of grains of a mono-phase structure is based on the idea of "geometric proportionality between the macro-movements in each section of the volume of deformed body and micro-movements of the grains in the structure of the body corresponding to this point" [23]. This means that if we determine movements by FEM in one of the deformed bodies, these movements can be brought through appropriate scale and geometric ratios to the microstructure corresponding to this point. Such an interpolation may seem very inaccurate, but modeling studies conducted to date with this method show that the accuracy of modeling deformation of grains is in the range of 18-22% [24, 25].

We will illustrate this idea in the case of deformation by flattening of a cylindrical sample (Fig. 1). Due to axis symmetry only a quarter of the specimen is shown in the meridian plane. In the non-deformed (0%) net of finite elements several of them are selected, such as items 1, 2, 3. For pre-selected degrees of deformation (10%, 20%, 30%, 40%, 50%) in the process of modeling by FEM the corresponding displacements of nodes at the tops and additional points on the sides of those elements are calculated.

We consider the displacements of the tops of one element of the net of finite elements for example element 1 of Fig. 1.

A mathematical model is made of the mathematical correlations between movements in the finite element of the macro level and moving the top of a geometrically similar element of the micro-level comprising a group of grains of real structure of a deformed body (Fig. 2a), which undergoes the same deformation equivalent to models of Fig. 1. This group was selected on grain metallographic micro section so that it is the area of element 1.

The grains are numbered as 1, 2, 3, …, n and on the line mark off each grain is chosen finite number of points 1^n, 2^n, 3^n, …, then their coordinates are determined (r_1^n, z_1^n), (r_2^n, z_2^n), (r_3^n, z_3^n), …, in a selected fixed coordination system ROZ (Fig. 2a). Designated points 1^n, 2^n, 3^n, … are also points on lines demarcate the grains adjacent to the n-th grain.

Since displacements of the top of the unit comprising the studied group of grains are defined (Fig. 2b), it is assumed that movements in the micro elements are determined by the same functions of the shape (under the theory of FEM), which are in force for the according finite element of macro level. Thus we can determine the movements at any point of the studied area, including points 1^n, 2^n, 3^n, ... As a result, these points are moved into positions $1n'$, $2n'$, $3n'$, ... and have the new coordinates $(r_1^n, z_1^n)'$, $(r_2^n, z_2^n)'$, $(r_3^n, z_3^n)'$, ... After connecting the points in their new positions, new lines are received, outlining the boundaries of grains. On Fig. 3 the results are shown of modeling deformation of the structure for the discussed example in the degree of deformation to 50%.

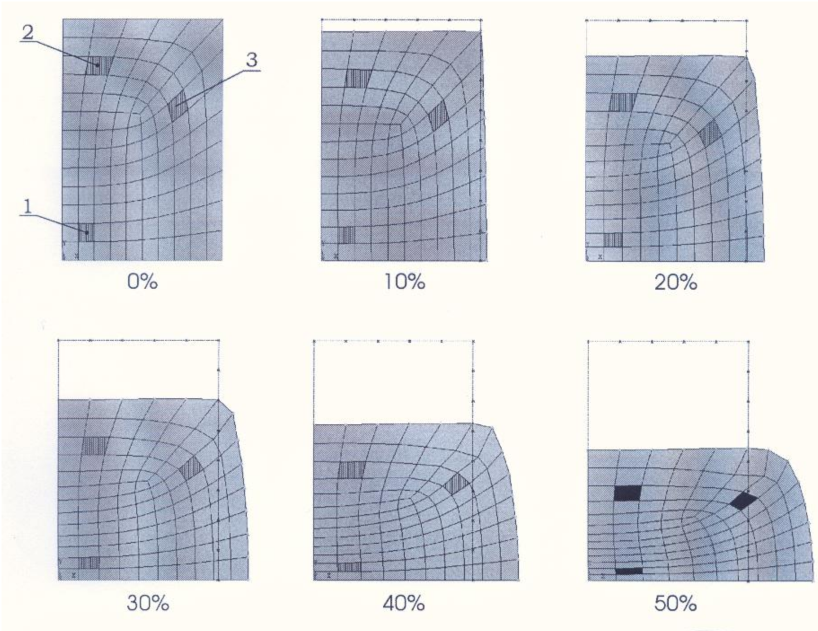
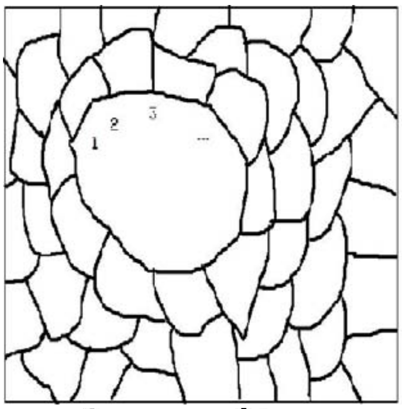


Fig. 1. A net of finite elements with flattening at different degrees of deformation, and fields marked by 1, 2, 3 which shape the structure



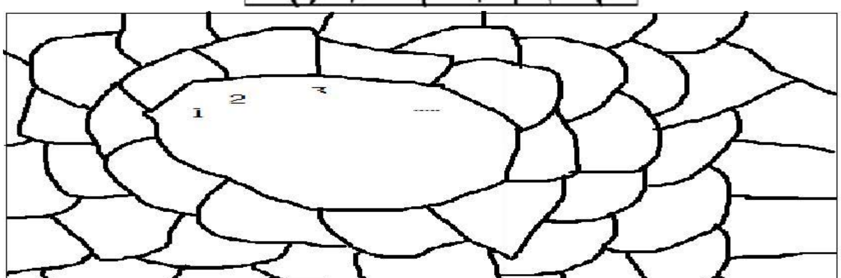


Fig. 2. A scheme for determining the shape of grains in an element of the net of finite elements: before deformation (a); after deformation (b)

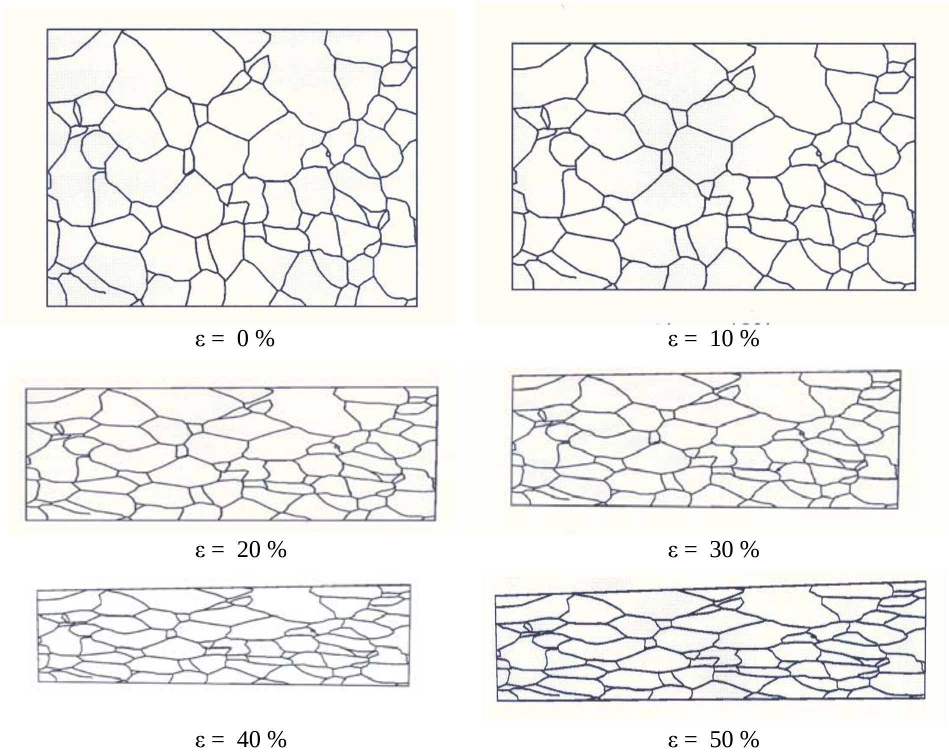


Fig. 3. Changes in the shape of grains in the area of item *1* of Fig.1 for various degrees of deformation of cylindrical specimen with a mono-phase structure (×200)

The methodology allows for each of the preliminary defined degree of deformation to perform an approximation by ellipses, then for each grain the following parameters are determined: the large diameter of ellipse *D*; the small diameter of the ellipse *d*; the angle *α*, that the large diameter *D* concludes with the positive direction of coordinate axis *R*.

The development of this project will enable the methodology to be further developed in the following areas:

- improvement of the mathematical model and the software, describing the deformation of grains in order to enhance the accuracy of modeling [26];
- development of a program module for calculating the principal deformation of each grain, based on the change of diameters *D* and *d* in the process of deformation;
- development of a software module to calculate the strengthening of any grain, as a result, distribution of mechanical properties in different areas of the distorted body can be predicted.
- based on the methodology set out herein we will develop a new methodology for modeling of grains deformation of two-phase structure, the new mathematical model and software for its implementation.
- the developing of the methodology will take into account the following characteristics of two-phase structures:

- different mechanical strength of the individual phases;
- various modules of strengthening;
- the course of the deformation process in the vicinity of different grains: the same phase and different phases;
- the course of the deformation process considering two-phase deformation of the whole conglomerate of grains.

As for the modeling of a mono-phase structure, we will develop software to calculate the main deformation and strengthening of each grain in the area of the structure.

The methodology for the work on the project includes also a methodology for assessing the accuracy of modeling. This is based on the methodology developed in [24, 25] approaches for evaluation of the modeling accuracy in different deformation processes. An extensive theoretical and experimental evaluation of the possibilities for their improvement will be carried out [27].

4. Conclusion

The following results are expected:

– mathematical models will be created of single grains deformation in real mono- and bi-phase structure;

– a copyright software will be created, working in conjunction with licensed commercial software, based on FEM, for modeling deformation of real grains of mono- and bi-phase metal structures;

– A methodology will be developed for determining the accuracy of the proposed model of grains deformation of a real structure in the process of cold plastic deformation;

– The accuracy of grain deformation modeling will be determined in mono- and bi-phase metal structures;

– Software will be developed to animate the process of grain deformation of a real mono- and bi-phase structures.

The effect of implementation consists in creating new software, working together with FEM software, which will allow modeling and visualization of each grain deformation in a mono- or bi-phase structure in the actual process of cold plastic deformation (in degrees of deformation of the specimen to 60%).

References

1. Saanouni, K. Virtual Metal Forming Including the Ductile Damage Occurrence – Actual State of the Art and Main Perspectives. – Journal of Materials Processing Technology, Vol. **177**, 2006, 19-25.
2. Gelin, J. C. Finite Element Analysis of Ductile Fracture and Defects for Deformation in Cold and Hot Forging. – Ann. CIRP, Vol. **39**, 1990, 215-218.
3. Boncheva, N., R. Iankov. Numerical Investigation of the Damage Processing in Metal Forming. – Eng. Frac. Mech., Vol. **40**, 1991, 387-393.

4. K i m, K. H., H. K. K i m, S. I. O h. Deformation Behavior of Pure Aluminum Specimen Composed of a Few Grains During Simple Compression. – Journal of Materials Processing Technology, Vol. **171**, 2006, 205-213.
5. B e a u d o i n, A. J. et al. Incorporating Crystallographic Texture in Finite Element Simulations of Sheet Forming. – Numisheet, Vol. **96**, 1996, 17-24.
6. F ü l ö p, T. et al. Size Effects From Grain Statistics in Ultra-Thin Metal Sheets. – Journal of Materials Processing Technology, Vol. **174**, 2006, 233-238.
7. B o n t c h e v a, N., G. P e t z o v. Phase Transformation During Metal Forming Processes. – In: Proc. Int. Conf. New Trends in Continuum Mechanics, Constanza, Romania, September 8-12, 2003, M. Mihailescu-Suliciu, Ed. Theta Series in Advanced Mathematics, 13-23.
8. B o n t c h e v a, N., P. P e t r o v, G. P e t z o v, L. P a r a s h k e v o v a. Finite Element Simulation of Strain Induced Austenite-Martensite Transformation and Fine Grain Production in Stainless Steel. – Computational Materials Science, Vol. **40**, 2007, No 1, 90-100.
9. S h e p p a r d, T. Prediction of Structure During Shaped Extrusion and Subsequent Static Recrystallisation During the Solution Soaking Operation. – Journal of Materials Processing Technology, Vol. **177**, 2006, 26-35.
10. B o n t c h e v a, N., G. P e t z o v. Microstructure Evolution During Metal Forming Processes. – Computational Materials Science, Vol. **28**, 2003, No 3-4, 563-573.
11. M a t h u r, K. K. P., R. D a w s o n. Texture Development During Wire Drawing. – ASME J. Eng. Mater. Technol., Vol. **112,** 1990, 292-297.
12. П е н ч е в, Т. Моделиране изменението на реалната форма на зърната в процеса на студена пластична деформация. – В: Международна научна конференция “Прогресивни машиностроителни технологии”, ноември 2005, Русе.
13. П е н ч е в, Т., С. Я н е в, И. А л т ъ п а р м а к о в, В. Д и к о в. Моделиране изменението формата на зърната в реалната структура на металите при изпитване на опън. – В: Международна научна конференция “Прогресивни машиностроителни технологии”, ноември 2006, Русе.
14. B o n t c h e v a, N., G. P e t z o v. FEM-Rationalized TEMPCOR-Process in Shape Rolling of Steel Rods. – In: Proc. of Int. Congress Mechanical Engineering Technologies, Varna, 2004, 64-67.
15. B o n t c h e v a, N., G. P e t z o v. Total Simulation Model of the Thermomechanical Process in Shape Rolling of Steel Rods. – Computational Materials Science, Vol. **34**, 2005, No 4, 377-388.
16. P e t z o v, G., N. B o n t c h e v a. Modelling of Thermomechanical Processing in Extrusion of Al-Alloys. – In: Proc. of 8th CIRP International Workshop on Modeling of Machining Operations, Chemnitz, Germany, May 10-11, 2005, 695-700.
17. B o n t c h e v a, N., G. P e t z o v, L. P a r a s h k e v o v a. Thermomechanical Modelling of Hot Extrusion of Al-Alloys, Followed by Cooling on the Press. – Computational Materials Science, Vol. **38**, 2006, 83-89.
18. P a r a s h k e v o v a, L., P. P e t r o v, N. B o n t c h e v a, G. P e t z o v. Finite Element Simulation of Gears Warm Die Forging. – Journal of Theoretical and Applied Mechanics, Vol. **37**, 2007, No 2, 33-44.
19. P a r a s h k e v o v a, L., N. B o n t c h e v a , V. I v a n o v, C h. S e c h e n s k i. Finite Element Simulation of Multiple Non-Mandrel Cool Extrusion of Copper Pipes. – In: Proc. of 10th Jubilee National Congress on Theoretical and Applied Mechanics, September 13-16, 2005, Varna, 306-311.
20. К у л е н, Т., О. Х о ф м а н, Р. К о п п, Г. К н е п п е, Х. П л о с е н е к, В. Х о н е т. Виртуальная реальность: разработка иновационных концепции установок. – Черные металлы, март 2005, 68-72 (перевод с немецкого).
21. Ш а м а р и, У. Установка CPS и киберпространство. – Черные металлы. Февруари 2005, 45-46 (перевод с немецкого).
22. G o t t s t e i n, G., V. M a r x, R. S e b a l d. Simulation of Primary Recrystallisation Using a Modified Three-Dimensional Cellular Automation. – Acta Mater, Vol. **4**, 1999, 1219-1230.

23. П е н ч е в, Т. Моделиране изменението на реалната форма на зърната в процеса на студена пластична деформация. – В: Научна сесия на Русенския университет, том **44**, 2005, серия 2, 181-185.
24. П е н ч е в, Т., С. Я н е в, С. А л т ъ п а р м а к о в, В. Д и к о в. Моделиране изменението формата на зърната в реалната структура на металите при изпитване на опън. – В: Научна сесия на Русенския университет, том **44**, 2005, серия 2, 186-190.
25. П е н ч е в, Т., С. Я н е в, Р. Л а з а р о в а, И. А л т ъ п а р м а к о в. Моделиране деформацията на зърната на реална стируктура при студена пластична деформация. – В: Доклади на Техническия университет, Пловдив. Том **13**. 2006.
26. M l a d e n o v a, C. Group Theory in the Problems of Modeling and Control of Multi-Body Systems. – Journal of Geometry and Symmetry in Physics, Vol. **8**, 2006, 17-121.
27. K a r a s t o y a n o v, D. Control of Mechatronic Systems. Sofia, Academic Publishing House "Prof. Marin Drinov", 2007.

Моделирование деформации зерн в процессе холодной пластической деформации

Тодор Пенчев, Димитр Карастоянов

Центральная лаборатория мехатроники и приборостроения, 1113 София

(Р е з ю м е)

В статье представлена разработка программного продукта для цифровой симуляции деформации зерн в процессе холодной пластической деформации. Это дает возможность прогнозировать изменения в структуре после деформации, т. е., прогнозировать как неравномерности свойств в объеме деформированного тела, так и эго структуру после рекристализационного отгрева.