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COMPUTER SIMULATION OF THE EXTRUSION PROCESS OF *Bi-Te* BASED THERMOELECTRIC MATERIAL OF RECTANGULAR SHAPE

During hot extrusion, the thermoelectric material heated to a temperature below its melting point passes through the mold (die) under the action of pressure. In the present paper, this process has been simulated with the use of Comsol Multiphysics application package of object-oriented simulation. In this model, the extruded material is presented as a liquid with a very high viscosity, which depends on the velocity and temperature. As a result of simulation, the distributions of temperature and material flow velocity in the die were obtained as well as stress distribution in the die due to external pressure and thermal loads during the tape extrusion process. These studies make it possible to optimize the installation for the production of extruded thermoelectric material. Bibl. 4, Fig. 6, Tabl. 2.

Key words: thermoelectric material, hot extrusion, computer simulation, die.

Introduction

There are various methods for obtaining thermoelectric materials, which are solid solutions based on bismuth telluride. These solutions have a number of specific features that make it difficult to obtain high- quality materials. Among the existing methods for obtaining thermoelectric materials, the most common is the method of zone melting, mainly vertical [1].

Another method for obtaining thermoelectric materials is the hot extrusion process when the thermoelectric material heated to a temperature below its melting point passes through the mold (die) under the action of pressure [2]. This method has the following advantages:

– High degree of homogeneity of the obtained samples.
– The ability to obtain samples of the required shape, which reduces the loss of material during further cutting.
– Higher mechanical strength of the samples compared to those obtained by zone melting.

However, the hot extrusion method also has disadvantages, the main of which is that texture in extruded materials is worse than in materials obtained by zone melting, but the figure of merit of extruded material is achieved not only by texture, but also by phonon scattering at grain boundaries [3].

Summarizing the advantages and disadvantages of the hot extrusion method, we can conclude that the materials obtained in this way have a high consumer potential. Thus, the main task in the study of the hot extrusion is to improve starting samples. This is achieved by optimizing the geometry of the die and experimenting with the input conditions of the process such as temperature, pressure and more. However, such experiments involve large financial and labor costs, which, as a result, may not be justified at all. To reduce these costs and formulate the theoretical part of this technology, computer simulation is a very relevant method. This method allows revealing critical shortcomings of the influence of conditions on the obtained samples. Of course, it is not able to reproduce real conditions of the hot extrusion with 100% reliability, but even the existing imperfect reliability can reduce costs several times.

The purpose of this work is to create a computer model of the process of hot extrusion of thermoelectric material based on bismuth telluride, in order to study the temperature distribution and the velocity of formation of extruded material in the form of tapes, which can be the basis for optimizing the hot extrusion work equipment.

Physical, mathematical and computer models

To accomplish this task, Comsol Multiphysics application package of object-oriented simulation was used [4]. In this model, the thermoelectric material is considered as a liquid with a high viscosity which depends on velocity and temperature. Computer model makes it possible to study the distribution of mechanical stresses in the die due to external pressure and loads.

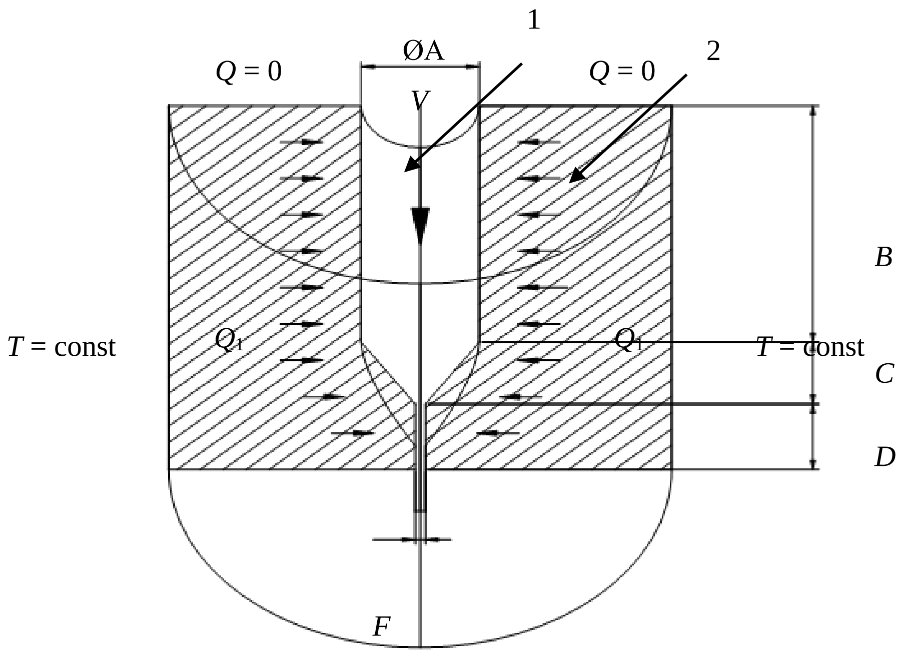

Fig. 1. Physical model of the extrusion process of tape thermoelectric material.

The used physical model of the tape material extrusion process is shown in Fig. 1. The model considers the case of extrusion of a cylindrical billet of material 1 through a matrix 2, at the output of which a tape of thermoelectric material is formed. The geometrical dimensions: A and B are the diameter and length of the input cell of the die in which the thermoelectric material billet is located; C is the length of the beveled part of the die; D and F are the thickness and length of the die outlet, the width of which is A. The case is considered when the ratio of the length to the thickness of the outlet is in the range 2 - 10.

During simulation, one also has to take into account a large number of parameters of the operating environment, some of which are shown in Table 1.

Table 1

Model environment conditions

1.	Ambient temperature	25˚C
2.	Die temperature (T = const)	450˚C
3.	Coefficient of heat exchange between the material and the die	11000 W/(m^2*K)
4.	The speed of the piston that presses material (V)	0.03 mm/s

The properties of thermoelectric material and the material of which the die is made are given in Table 2.

Table 2

Material properties

1.	Thermoelectric material	Thermal conductivity, W/(m*K)	4
		Density, kg/m^3	7600
		Heat capacity, J/(kg/K)	150
2.	Steel (die)	Thermal conductivity, W/(m*K)	24.3
		Density, kg/m^3	7850
		Heat capacity, J/(kg/K)	500

Fig. 2 shows a grid of the investigated model in Comsol Multiphysics.

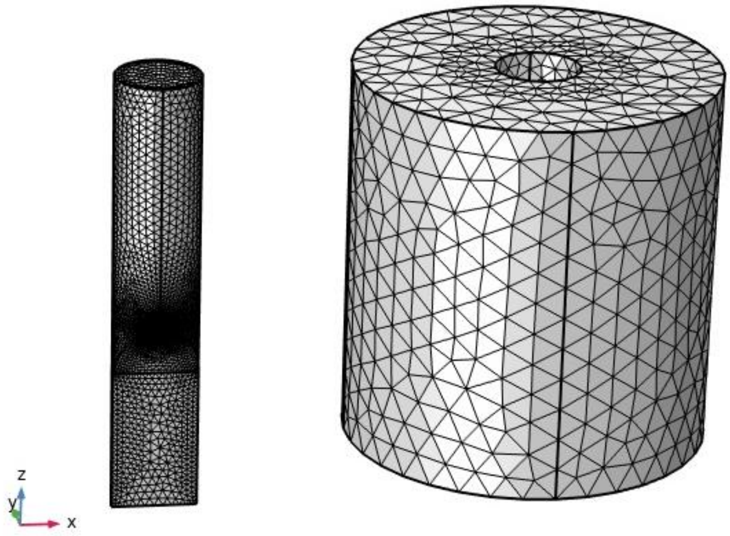

Fig. 2. The grid is built for the die configurations shown in Fig.1.

Computer simulation results

As a result of computer simulation, the following indicators were obtained:

Velocity field of thermoelectric material inside the die is shown in Figs.3 and. 4.

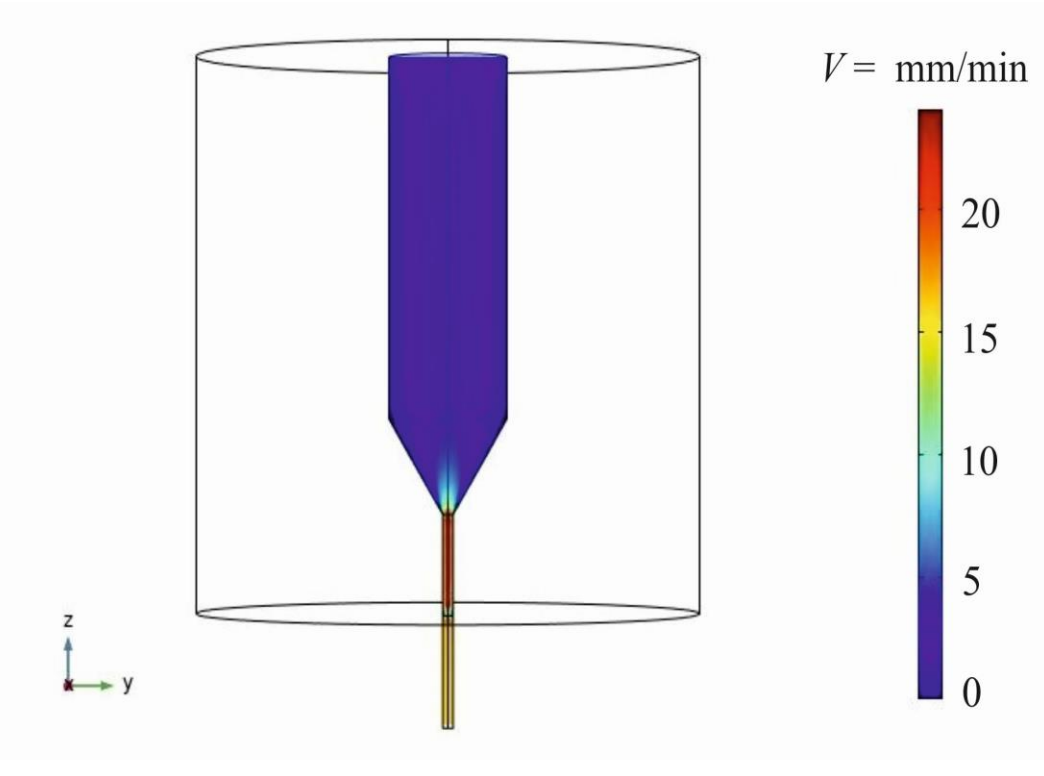

Fig. 3. Velocity field of thermoelectric material

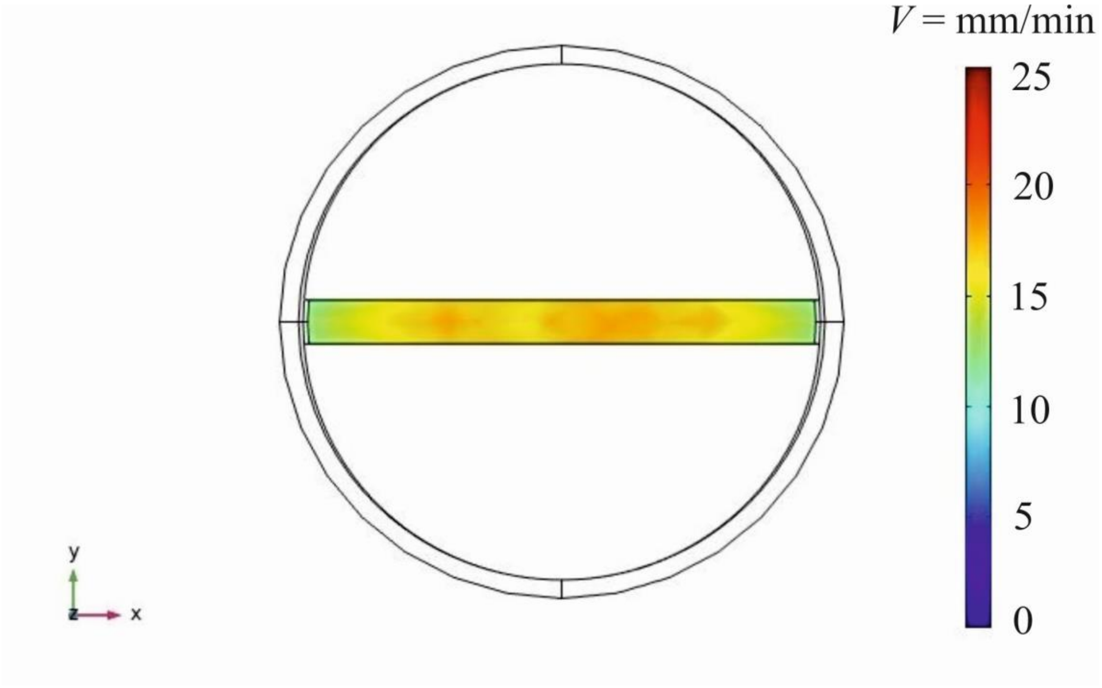

Fig. 4.Velocity field of thermoelectric material at the output

Temperature distributions in thermoelectric material and die are shown in Figs. 5 and 6.

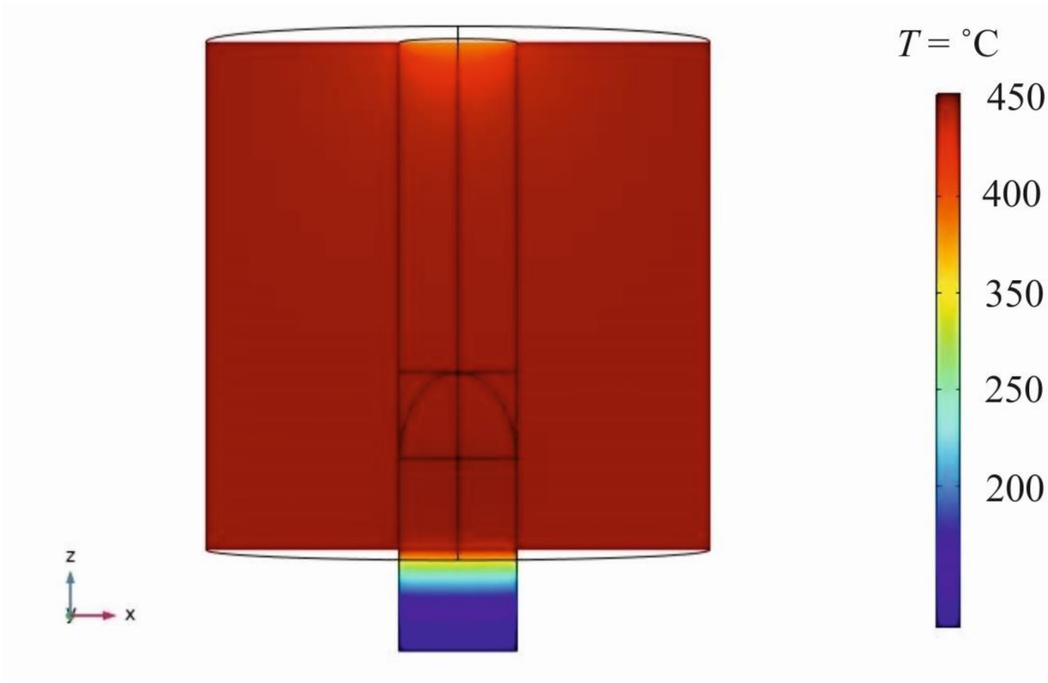

Fig. 5. Temperature distributions

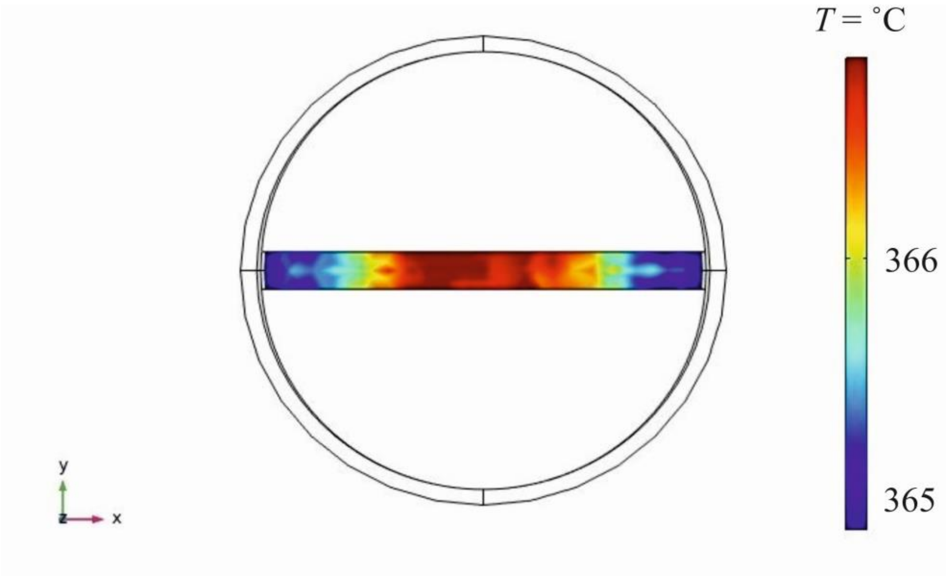

Fig. 6. Temperature distributions at the output

The developed computer model can serve as a basis for optimizing the installation for extrusion of thermoelectric material based on bismuth telluride in order to increase its efficiency, as well as to improve starting product.

Conclusions

1. A computer model of the process of hot tape extrusion of a thermoelectric material based on bismuth telluride has been created, which can be used to study the distributions of temperature and velocity of material movement in a die of a given shape, as well as the distribution of stresses in the die due to external pressure and thermal loads.
2. The behavior of thermoelectric material passing through the die for the case of tape extrusion of thermoelectric material based on bismuth telluride has been studied.
3. The distributions of temperature and velocity fields have been obtained depending on the configuration of the die for the case of one-stage tape extrusion of a thermoelectric material based on bismuth telluride.

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КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ ПРОЦЕСУ ЕКСТРУЗІЇ ТЕРМОЕЛЕКТРИЧНОГО МАТЕРІАЛУ НА ОСНОВІ *Bi-Te* ПРЯМОКУТНОЇ ФОРМИ

Процес гарячої екструзії являє собою проходження розігрітого до температури нижче температури плавлення термоелектричного матеріалу через прес-форму (філь'єру) під дією тиску. В даній роботі проведено моделювання цього процесу з використанням пакету прикладних програм об'єктно-орієнтованого моделювання Comsol Multiphysics. В даній моделі екструдованих матеріал представляється як рідина з дуже високою в'язкість, яка залежить від швидкості та температури. В результаті моделювання було отримано розподіли температури й швидкості течії матеріалу в матриці, а також розподіл напруг у матриці за рахунок зовнішнього тиску і теплових навантажень в процесі стрічкової екструзії. Дані дослідження дають змогу оптимізувати установку для одержання екструдованого термоелектричного матеріалу. Бібл. 4. рис. 6, табл. 2.

Ключові слова: термоелектричний матеріал, гаряча екструзія, комп'ютерне моделювання, філь'єра.

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССА ЭКСТРУЗИИ ТЕРМОЭЛЕКТРИЧЕСКИХ МАТЕРИАЛОВ ПРЯМОУГОЛЬНОЙ ФОРМЫ НА ОСНОВЕ *Bi-Te*

Процесс горячей экструзии представляет собой прохождение разогретого до температуры ниже температуры плавления термоэлектрического материала через пресс-форму (фильеру) под действием давления. В данной работе проведено моделирование этого процесса с использованием пакета прикладных программ объектно-ориентированного моделирования Comsol Multiphysics. В данной модели экструдированный материал представляется как жидкость с очень высокой вязкостью, которая зависит от скорости и температуры. В результате моделирования было получено распределения температуры и скорости течения материала в матрице, а также распределение напряжений в матрице за счет внешнего давления и тепловых нагрузок в процессе ленточной экструзии. Данные исследования позволяют оптимизировать установку для получения экструдированного термоэлектрического материала. Библ. 4, рис. 6, табл. 2.

Ключевые слова: термоэлектрический материал, горячая экструзия, компьютерное моделирование, фильеры.

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