Publishing House
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE

Informatyka w Technologii Materiałów

Vol. 13, 2013, No. 3

FINITE ELEMENT ANALYSIS OF THE PILLAR-GUIDE TOOL SETUP OF THE MACHINE FOR MICROFORMING PROCESSES#

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Abstract

In contrast to traditional manufacturing applications, small-scale manufacturing processes usually require sophisticated equipment which is generally associated with high costs and low productivity. Current trends suggest manufacturing metallic parts by 'microforming'. Microforming is a well suited technology, in particular in case of mass production, of very small metallic parts required in many industrial products and resulting from widespread application of micro technology. Fundamental issues and problems in the micro world are connected with processes, forming tools, construction of the machines, handling of micro parts, equipment and also with material. The dimensions of micro machines are much smaller than those of conventional large-scale presses. The development of such machines has attracted a lot of interest from researchers for many years. The purpose of this study was to optimize a tool system concept and to investigate its stiffness. FEM analysis was carried out to receive the theoretical stiffness. For receiving experimental stiffness laser interferometer was used. Based on experimental and FEM results it can be concluded that the designed tool system is useful for microforming processes.

Key words: microforming, stiffness, FEM analysis, tool system

1. INTRODUCTION

Over the years, the need to develop micro parts has increased significantly. Manufacturing of metallic parts by forming methods is widely propagated in industry due to good surface quality, high accuracy or good efficiency at concurrent high quantity. Despite their numerous advantages, micro parts are mainly produced by machining, because of micro scale problems mostly caused by size-effects (Chan & Fu, 2011; Jiang et al., 2012). These effects occur by scaling down geometry and process parameters. Fundamental issues and problems in the micro world are connected not only with material, but also with processes, forming-tools, construction of the machines, handling of micro parts or equipment (Jeswiet et al., 2008). In spite of all these problems, microforming is a well suited technology for manufacturing, in particular for mass production, of very small metallic parts required in many industrial products and resulting from widespread application of micro technology (Ghassemali et al., 2012).

In contrast to traditional manufacturing applications, small-scale manufacturing processes usually require sophisticated equipment, which is generally associated with high costs and low productivity. The dimensions of micro machines are much smaller than those of conventional large-scale presses. The development of such machines has attracted a lot of interest from researchers over the last years. It is important to design and manufacture such machines properly and accurately. Thus, many authors investigate the stiffness of machine (Qin et al., 2008; Kim

#This paper was presented at the KomPlasTech 2013 Conference, which was held in Zakopane, Poland on January 13-16, 2013

 ISSN 1641-8581

et al., 2008; Ou et al., 1999), which directly affects the forming processes.

The purpose of this study was to optimize a tool system concept based on several numerical simulations and to investigate the stiffness of this tool system. Theoretical stiffness was received by carrying out the FEM simulations. Thanks to special testing-bench equipped with a laser interferometer, an experimental stiffness was received. Based on both experimental and FEM results it can be concluded that the designed and manufactured tool systems are useful for microforming processes. Proper machine design greatly improves microforming processes and consequently the product quality.

2. TOOL SYSTEM DESCRIPTION

In order to obtain micro parts, a machine for microforming processes was constructed. In the course of the research several design solutions were modeled and then analyzed. The study was based on two optimization criteria: the height of pillars and the width of pillars. Each time, the longitudinal displacement was measured depending on either the height or the width of pillars. Figure 1 shows the relationship between the height of pillars and the longitudinal displacement. Figure 2 presents the optimized design of the machine. Overall dimensions of the selected tool system are 200 mm x 315 mm x 245 mm. To achieve the specified accuracy, special parts such as MillionGuide System (figure 3) or tool guide system were used.

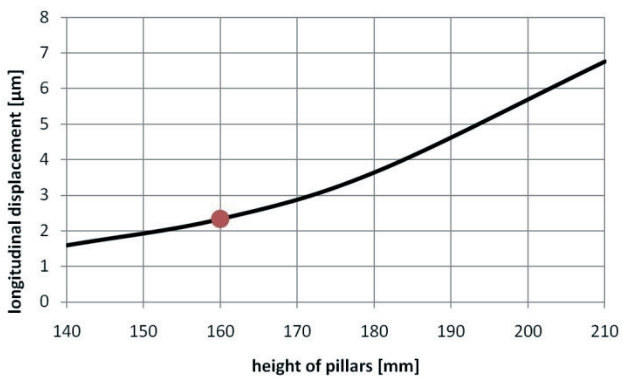

Fig. 1. Height of pillar – longitudinal displacement curve

The machine was designed to perform the following three processes of metal plastic forming: deep drawing process, extrusion process and cutting process.

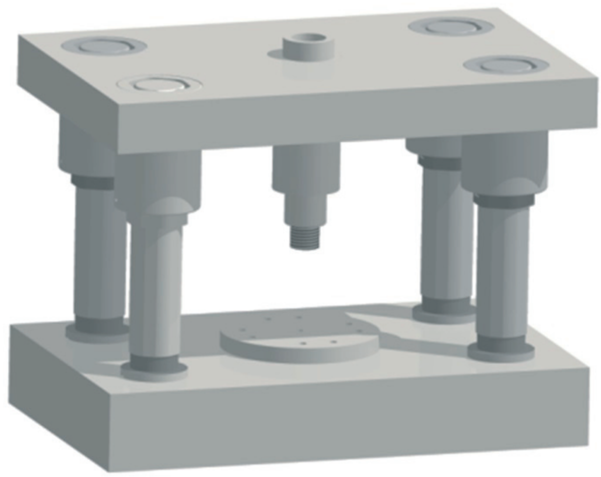

Fig. 2. CAD model tool system

Fig. 3. MillionGuide System.

3. STIFFNESS ANALYSIS

3.1. Numerical simulations

Prior to the project design implementation of the machine for microforming, numerical simulations of the tool system loading were performed with MSC.MARC software. Each simulation was made for models built of solid 3D finite elements. Tool system geometry was applied to the FE software from CAD software. The boundary conditions were selected for each simulation according to the principles of load acting upon the tool system in the process of microforming. The side loads (figure 4) were specially considered since they seemed to exert strong influence upon accuracy of the finished micro product. The entire assembly is shown in figure 5. The model of elastic material was established for the whole assembly. Young's modulus is $2{\cdot}10^5$ MPa and Poisson ratio equals 0.3. Moreover, the forces from weight of the tool system were determined, including mass and acceleration due to gravity. Different boundary conditions for loading in the tool system such as longitudinal force, cross force and diagonal force were simulated. The main problem was to estimate the stiffness of the tool system with loadings perpendicular to the workload (side force direction). Issues related to connection of pillars with sleeves and connection of pillars with the bottom plate of the tool system were of great importance for stiffness. In the simulations, points of contact in rollers, which are located between the sleeve and the pillar (MillionGuide System) were neglected (figure 5a). Instead, the surface contact was established. For all contact pairs of elements (except sleeve-pillar contact) – type 'glue' (MSC MARC contact type) the contact terms and conditions were determined. These connection conditions are simplified. Complete FE model of the tool system consists of 64 056 elements and 88 698 nodes.

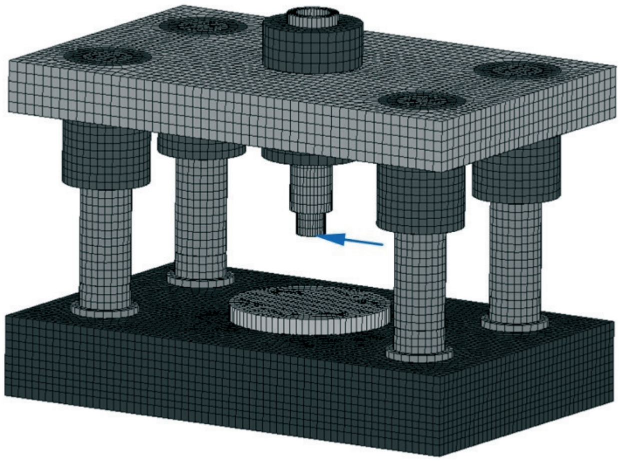

Fig. 4. *FEM model and boundary conditions of loading*

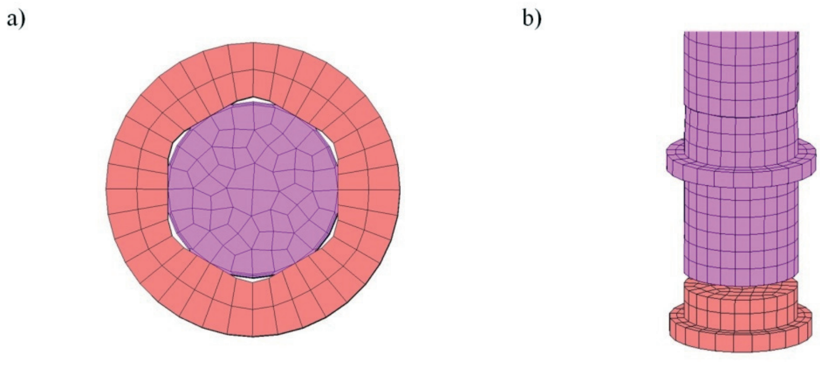

Fig. 5. *Sleeve and pillar connection: a) view of the sleeve shape, b) pillar - plate assembly of tool system.*

Fig. 6. *Real image of the tool system*

3.2. Experimental investigations

After the appropriate optimization of the machine design, the real tool system (figure 6) was accomplished and subjected to experimental stiffness tests. In comparison with traditional measuring methods, laser systems makes it easier to obtain considerably more accurate and repeatable results. Therefore, laser interferometer method was chosen to investigate the experimental stiffness of the machine for microforming processes. The investigations were carried out with the application of Lasertex laser interferometer LSP30-3D. A complex device is designed for laser interferometer measurements and mainly destined for linear interferometric measurements performed in the machine industry. The scheme presented in figure 7 shows that the force was generated by using a screw with a nut (8). Dynamometer (7) was attached to the tool holder (6) (or between the end of the screw and the upper plate of the tool system (5)). Dynamometer was connected with Spider 8 measurement system (9). Displacement of the upper plate of the tool system was measured by laser interferometer (3). For this purpose roto linear reflector (4) was attached to the upper plate. Laser beam was emitted from the laser head to the optical system. The values were transferred on the computer (1), which also controls the interferometer. The tool displacements were performed in a few directions.

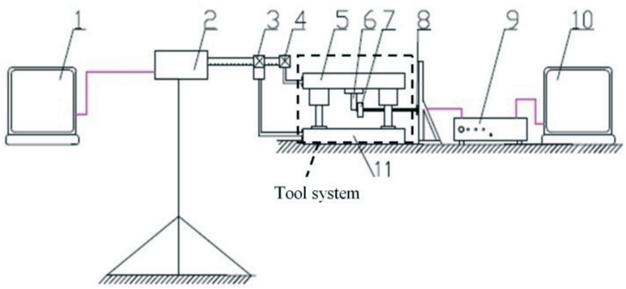

Fig. 7. Scheme of apparatus for stiffness analysis: 1) laptop with laser interferometer software, 2) laser head LSP30- 3D, 3) linear interferometer, 4) roto linear reflector, 5) upper plate of tool system, 6) tool holder, 7) dynamometer Megatron KMB52, 8) screw with nut, 9) Spider 8 system for force measurement , 10) laptop with Spider 8 software, 11) bottom plate of tool system.

4. COMPARISON OF RESULTS

The aim of both numerical simulations and experimental tests was to investigate the stiffness of the tool system in microforming processes. In both cases the tool holder was loaded with side (longitudinal) force (see figure 4), that was increasing to the value of 300 N. FEM results of longitudinal displacements were shown in figure 8.

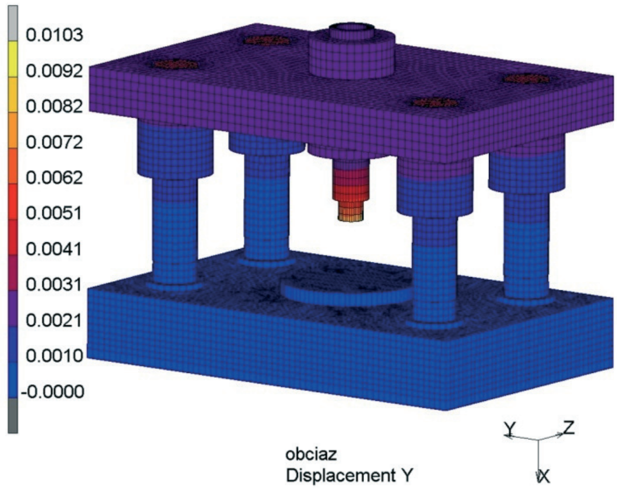

Fig. 8. FEM results of displacements in the machine for microforming with loading of longitudinal force attached to the tool holder.

Distributions of displacements in both FEM analysis and experimental tests, are collated in figure 9. FEM analysis made it possible to read the data from both the tool holder and the plate (upper). Dispalcement of the plate was the only measurement in the experimental test that was possible to be read. The results prove that relatively greater stiffness was observed in FE simulation at the displacement of 2.5 µm. The displacement of the upper plate from experimental tests was 5µm. However, the results measured in microns depend largely on the forces of individual elements of contact pairs generated during the assembly process. Apparently, the difference is as high as 50%, but it still amounts only to 2.5 microns, which is insignificant in case our plastic forming processes are implemented. Maximum longitudinal displacement of tool holder from FEM analysis is about 10 microns.

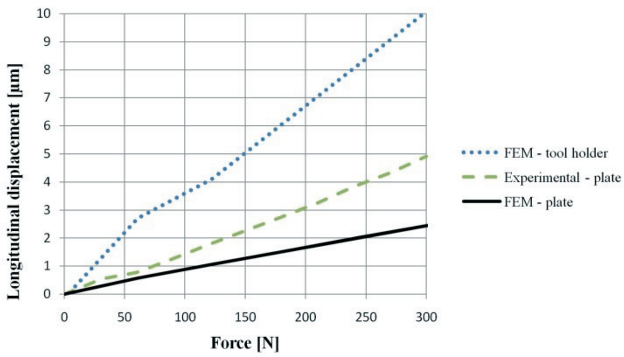

Fig. 9. Force – displacement curves of experimental and FEM results.

5. SUMMARY AND CONCLUSIONS

In order to create a machine for carrying out the microforming processes, several constructional solutions were designed. Each suggestion was then analyzed using numerical simulations. FEM results made it possible to select the optimal design which was subsequently implemented. On the chosen machine concept, two methods of stiffness tests were performed: with the application of FEM and experimental apparatus with laser interferometer. FEM and experimental results were then compared. In both cases the tool holder was loaded with longitudinal force that kept increasing to the value of 300 N. Based on the obtained stiffness curves it was possible to conclude that theoretical stiffness of the plate (displacement equals 2.5µm) is greater than the experimental one (displacement equals 5µm). Simplified FEM model is responsible for such results. The results measured in microns depend largely on the forces of individual elements of contact pairs generated in the course of assembly process. Maximum longitudinal displacement of the tool holder from FEM analysis is about 10 microns. Tested stiffness of the tool system is more than sufficient for microforming processes and can be acceptable in both cases. Simulations of selected boundary conditions of loading show much less side forces on the tool holders than those which have been accepted in experimental investigation of stiffness. Based on FEM and experimental analysis it can be concluded that the tool system was properly designed.

ACKNOWLEDGEMENTS

The work was financed as a research project no N N 503 206 240 by the National Science Center - Poland.

The authors gratefully acknowledge the technical support of the Danfoss Poland Tooltip Group under the leadership of Piotr Siwiec, which supported the research project.

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ANALIZA MES PRZYRZĄDU WCHODZĄCEGO W SKŁAD MASZYNY DO REALIZACJI PROCESÓW MIKROFORMOWANIA

Streszczenie

Ciągły wzrost popytu na miniaturowe części, takie jak na przykład: mikrośruby, mikronarzędzia, czy mikroimplanty - stosowane w inżynierii biomedycznej, powoduje szybki rozwój metod mikroformowania z zastosowaniem obróbki plastycznej. W przeciwieństwie do tradycyjnych zastosowań produkcyjnych, procesy produkcyjne elementów w małej skali wymagają przeważnie skomplikowanego sprzętu, co wiąże się z wysokimi kosztami i niską wydajnością. Mikroformowanie jest odpowiednią technologią do produkcji bardzo małych metalicznych elementów, zwłaszcza w przypadku produkcji masowej. Podstawowe zagadnienia i problemy w „mikroświecie" są głównie zawiązane z samym procesem technologicznym, narzędziami, konstrukcją, sprzętem, a także z samym materiałem.

Mikromaszyny mają znacznie mniejsze wymiary niż konwencjonalne maszyny. Zainteresowanie nimi znacznie wzrosło w ciągu ostatnich lat. Celem pracy jest optymalizacja koncepcji przyrządu wchodzącego w skład urządzenia do mikroformowania w oparciu o symulacje numeryczne oraz wyznaczenie jego sztywności. Sztywność teoretyczna została wyznaczona przy zastosowaniu analizy MES. Przy użyciu interferometru laserowego na specjalnie zaprojektowanym stanowisku badawczym możliwe było wyznaczenie eksperymentalnej sztywności. Badanie sztywności nowego urządzenia ma duże znaczenie, ponieważ w głównej mierze to od niej zależy prawidłowy przebieg procesów formowania, a także jakość wykonanych elementów. Na podstawie wyników doświadczalnych i numerycznych potwierdzono przydatność zaprojektowanego i wyprodukowanego przyrządu do zastosowań mikroformowania.

Received: May 13, 2013
Received in a revised form: July 17, 2013
Accepted: October 2, 2013