Tolerance analysis in manufacturing using process capability ratio with measurement uncertainty

Tolerance analysis provides valuable information regarding performance of manufacturing process. It allows determining the maximum possible variation of a quality feature in production. Previous researches have focused on application of tolerance analysis to the design of mechanical assemblies. In this paper, a new statistical analysis was applied to manufactured products to assess achieved tolerances when the process is known while using capability ratio and expanded uncertainty. The analysis has benefits for process planning, determining actual precision limits, process optimization, troubleshoot malfunctioning existing part. The capability measure is based on a number of measurements performed on part’s quality variable. Since the ratio relies on measurements, elimination of any possible error has notable negative impact on results. Therefore, measurement uncertainty was used in combination with process capability ratio to determine conformity and nonconformity to requirements for quality characteristic of a population of workpieces. A case study of sheared billets was described where proposed technique was implemented. The use of ratio was addressed to draw conclusions about non-conforming billet’s weight expressed in parts per million (ppm) associated with measurement uncertainty and tolerance limits. The results showed significant reduction of conformance zone due to the measurement uncertainty.

Inner centering in parting line area of injection mould using side locks

Injection moulding is characterized by high precision requirements. In particular, the demands regarding the mould plates alignment are in order of few micro meters. This research introduces a methodology to measure the misalignment in injection moulding. Eddy current sensors are used in the system to perform measurements for a whole cycle. In a long run of the mould, a comparison of mould deviation between the first and the last cycles is obtained.
Strength analysis and modeling of cellular lattice structures manufactured using selective laser melting for tooling applications

Additive manufacturing is rapidly developing and gaining popularity for direct metal fabrication systems like selective laser melting (SLM). The technology has shown significant improvement for high-quality fabrication of lightweight design-efficient structures such as conformal cooling channels in injection molding tools and lattice structures. This research examines the effect of cellular lattice structures on the strength of workpieces additively manufactured from ultra high-strength steel powder. Two commercial SLM machines are used to fabricate cellular samples based on four architectures—solid, hollow, lattice structure and rotated lattice structure. Compression test is applied to the specimens while they are deformed. The analytical approach includes finite element (FE), geometrical and mathematical models for prediction of collapse strength. The results from the the models are verified with experimental data and it is shown that they agree well. The results from this research show that using lattice structures significantly reduces the strength of material with respect to solid samples while indicating no serious increase of strength compared to hollow structures. In combination with an analysis of microstructures, a description of strength analysis is obtained with respect to process parameters.

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The influence of cellular structures on flow stress of high strength components manufactured using SLM

Additive manufacturing has shown significant improvement in material and machines for high-quality solid freeform fabrication processes such as selective laser melting (SLM). In particular, manufacturing lattice structures using the SLM procedure is of interest. This research examines the effect of cellular materials on compression strength. The specimens are manufactured additively using industrial 3D printing systems from high-strength alloy. The material has the right mechanical properties for manufacturing tool components. This includes samples with solid and lattice structures. The Compression tests are applied to the both samples while they are deformed. The flow stress curves from this research show that using cellular material significantly reduces the yield stress of the samples. This reduction compromises the efficiency of the new structure with respect to the material save.

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Elastic deflection and tilting effect in a multi-stage micro bulk former

Previous studies have described a high performance transfer press for the application in micro forming. This research extends this finding by conducting a two-stage forming process for the machine tool in order to examine the efficiency of the machine in a real multi-stage process. In particular the analysis focuses on quantifying the effect the forming force has on the elastic deflection of the machine and the tools by examining the displacement of the moving plate under loaded and unloaded conditions. The results of the measurements were used to describe the tilting effect due to the off-center loading applied to the upper tool plate.

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Hot embossing and mechanical punching of biodegradable microcontainers for oral drug delivery

A process has been developed to fabricate discrete three-dimensional microcontainers for oral drug delivery application in Poly-L-Lactic Acid (PLLA) polymer. The method combines hot embossing for the definition of holes in a PLLA film and mechanical punching to penetrate the polymer layer around the holes, after filling them with drug. Here, we demonstrate the fabrication of microcontainers with a diameter of 340 μm and a height of 50 μm. The process is temperature benign so that the compositional integrity of the drug is preserved. It also provides a good flexibility for creating different sizes and shapes of microcontainers. Finally, the process is compatible with roll-to-roll processing that could lead to low cost high volume production. © 2014 Elsevier B.V. All rights reserved.

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Precision analysis in billet preparation for micro bulk metal forming

The purpose of this research is to fabricate billets for an automated transfer press for micro forming. High performance transfer presses are well-known in conventional metal forming and distinguished from their automation and mass production. The press used in this research is a vertical mechanical press. When using a vertical mechanical press, the material is fed as billets into the forming zone. Therefore, a large number of highly uniform billets are required to run mass production in such a setup. Shearing technique was used for manufacturing the billets. The efficiency of the shearing tool is examined in terms of volume control, circularity, dimension and sheared surface quality. The shearing tool is based on holders for both bar and cutoff. The tool is fixed in dimensions, since the dimensions of billets are fixed throughout experiments of this research. The paper presents the experimental analysis of the precision of the billets prepared by the tool.

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Characterization of precision of a handling system in high performance transfer press for micro forming

Multi-step micro bulk forming is characterized by complex processes and high precision requirements. In particular the demands regarding handling accuracy between different forming steps are of the order of a few mm. The paper introduces a methodology for the analysis and characterization of this transfer system on component level and system level. Laser interferometry is used in combination with analytical models to predict the positioning ability of the actuator in a static as well as dynamic mode. In combination with an analysis of the grippers, a full description of the transfer precision inside the forming press is obtained. © 2014 CIRP.

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High Performance Transfer Press for Precision Manufacturing of Micro Metal Parts: Micro Forming Technology, Precision Engineering
Micro forming technology has several notable benefits such as yielding remarkable accuracy, high production speed, material saving and good mechanical properties of formed parts which allows complex micro parts to be manufactured by this technology. There are also presses fabricated appropriately for this technology and are available already in the market. Similar to conventional forming processes, the presence of a handling system can significantly improve the efficiency of the technology towards building a high performance transfer press for micro forming technology. To examine this possibility, it is important to investigate the process parameters such as billet preparation, automation, forming machine and forming process which influence on geometrical accuracy and surface quality of formed parts. Previous studies have indicated handling devices for micro forming based on different strategies and handling concepts. The aim of this research primarily is to develop an integrated solution for micro metal forming based on a flexible tool with integrated handling operations. The study herein extends these finding by designing and implementation of a multi-step micro metal forming process based on the above developed handling solution including a fully instrumented flexible tool for micro metal forming with the above mentioned characteristics.

For this research, the 1050 Aluminum Alloy was used for forming material while it is originally in the form of coil. This original stock was sectioned into the necessary size for billet preparation. The analysis of the prepared specimens focused on establishing the effect the shearing process has on the precision of billet by examining the length and weight of sheared specimens. To observe possible defects on the cut edge, the sheared surfaces were tested for measuring the ovality of the sheared surfaces. An upsetting test was used to determine the flow stress curve of the material. Additionally, the initial condition of specimens were indicated for roughness and microstructure parameters.

A transport device was manufactured which consisted of a linear motor for actuation principle and mechanical grippers based on self-centering and friction principles. This study introduced a methodology for the analysis and characterization of this transfer system on component level and system level. Laser interferometry was used in combination with analytical models to predict the positioning ability of the actuator in a static as well as dynamic mode. In combination with an analysis of the grippers, a full description of the transfer precision inside the forming press was obtained.

The current research involved integration of a handling system into an existing developed micro press in order to maximize the output rate up to 250 strokes per minute without compromising accuracy. A thorough investigation of machine’s layout and electrical circuit was conducted by combining two drives with ejection system for the new development of high performance transfer press. A transfer study was carried out on the basis of optimal dynamic parameters for the press and the manipulator. Through the application of high speed camera, the effect of proposed mechanism was studied on the flow of process in order to ensure an automated production as fast and smooth as possible for uninterrupted motions.

Consequently, the capability of the newly developed machine tool was examined by implementing a proposed two-operation micro cold forging process. Empirical knowledge and developed methods were obtained for manufacturing optimal front profile of the grippers in respect to the geometry of forged parts in each forming operation. While introducing a two-step forming process, process parameters such as tooling material, forming force, surface roughness of forming tools, lubrication and material flow were investigated.

The work was concluded with a recent high performance transfer press for micro forming technology in which all operations are automatic: feeding and transportation of specimens, press force and stroke control, part ejection and extraction of finished parts as well as monitoring and control of the entire transfer press. The effectiveness of the machine was analyzed in conjunction with the dynamic performance of feed drive, off-center loading and elastic deflection while introducing the errors due to the tool wear and thermal behavior of the system. Finally, the machine tool proved to be successful with respect to the concepts applied to the whole system for automatic production.

**Towards Mass Production by High Performance Transfer Press in Micro Bulk Forming**

Multi-step micro bulk forming is characterized by complex processes and high precision requirements. Several process parameters influence on accuracy of micro forged parts where small tolerances in the order of few μm are in demand. The paper introduces a high performance transfer press for micro cold bulk forming. A methodology for selection of linear motors on the bases of the process parameters was obtained. In order to examine the effectiveness of the machine, specific geometry was investigated for production. Kinematic parameters were found for a production rate of 200 strokes per minute. A forged part with three different diameters in height was produced in a two-stage forming process using the introduced transfer press.

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**Towards Mass Production by High Performance Transfer Press in Micro Bulk Forming**

Multi-step micro bulk forming is characterized by complex processes and high precision requirements. Several process parameters influence on accuracy of micro forged parts where small tolerances in the order of few μm are in demand. The paper introduces a high performance transfer press for micro cold bulk forming. A methodology for selection of linear motors on the bases of the process parameters was obtained. In order to examine the effectiveness of the machine, specific geometry was investigated for production. Kinematic parameters were found for a production rate of 200 strokes per minute. A forged part with three different diameters in height was produced in a two-stage forming process using the introduced transfer press.

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Many fasteners used in electromechanical systems are micro metal parts which should be manufactured with high accuracy and reliability and in large quantities. Micro forming is promising to fulfill these demands. This research focuses on investigating a gripping unit in a multi stage former, as the positioning unit was discussed earlier. The parameters which play important roles in the gripping unit will be discussed and the precision and reproducibility evaluated to show the performance of the unit. This includes two different tests. The first test will show how accurately the unit can locate the parts and the second one is intended to depict how the unit transfers the parts with different diameters with respect to the back profile of the fingers. The experiments showed that the manipulator can handle the parts with 7 μm accuracy, 2 μm reproducibility and 9μm uncertainty for a 20mm distance between two adjacent stations. Copyright © 2013 Trans Tech Publications Ltd.
A motion study of a manipulator for transferring microparts in a multi stage former

In the earlier studies, it was shown that a whole multi stage former can be divided into three major sub-sections, the positioning unit, the gripping unit and the forming unit. The two first units were investigated and related parameters and features of each were discussed. This research herein deals with the forming unit. For this research, the positioning unit and the gripping unit are applied to the forming unit including a micro press equipped with a die system. The analysis focuses on verifying the results already extracted from previous researches by implementing all mentioned units together. A motion study of the system gives an overview of different steps and movements inside the multi stage former. Significantly, increasing the production rate increases the acceleration and also causes the time frame tight. The time limitations put overlaps on the moving parts in terms of milliseconds. A high speed camera was used in the experiments with high resolution to show the details of the motion while enabling to detect any unwanted movement within milliseconds. Importantly, increasing the frequency of image capturing within the movement is another beneficial feature in the high speed camera in order to give sufficient information on critical movements where they may need sensors and enough time to ensure getting at the right position as programmed. In this research the production rate raised to 169 strokes per minute. The results show that the concept introduced for the manipulator works very well at a real process implementation. This significantly approves the techniques already were given to evaluate the precision in the positioning unit and the gripping unit. Copyright © 2013 by ASME.

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A New Approach for Handling of Micro Parts in Bulk Metal Forming

During last 10 years a lot of research has been done in micro forming processes. In spite of the challenges micro forming has in process, material properties, tooling technology and machines, micro forming technology yields remarkable accuracy and good mechanical properties with high rate of production [1]. This can fulfill the demands for mass production and miniaturization in industries and academic communities. According to the recent studies, topics related to materials, process and simulation have been investigated intensively and well documented. Machines, forming tools and handling systems are critical elements to complete micro forming technology for transferring knowledge to industries and toward miniature manufacturing systems (micro factory) [2]. Since most metal forming processes are multi stage, making a new handling system with high reliability on accuracy and speed is required. The handling system for micro parts should provide good precision and reproducibility with high speed and acceleration for gripping and positioning micro parts in the right place within few micron tolerances. Nowadays, many handling systems have been developed; either the conventional systems have been optimized or handling systems based on new concepts for gripping and releasing micro parts have been proposed. Making a handling system for micro parts made by sheet metals or foils is easier than those in bulk metal forming because parts are attached to the sheet during the forming process. Geiger made a prototype with vacuum gripper which enables transport of 260 parts per minute; with the length of 25 mm and the part diameter 0.85 mm and the accuracy of 5μm in positioning [3]. Wafios AG built up a multi station former with output rate of 400 strokes per minute and parts with diameter down to 5mm [4]. In addition IPU made a manipulator for micro parts for a multi stage bulk metal forming process [5]. This handling system works based on tension forces of viscous lubricant. Generally, conventional systems do not meet the requirements for accuracy in the micro domain, not only sticking forces are predominant compared to the weight of parts, but also small surfaces make gripping more difficult. Moreover, they have to position micro parts above forming dies in high acceleration within few microns. Backlashes and clearances which are not so important in the conventional handling systems must be considered in the manipulators for micro parts. So currently the trend for the design of micro manipulators is to reduce the size of them, simplify their design and make them more flexible to be able to include a wide range of products. This paper presents an approach for making a linear transportation system for bulk micro parts in a multi station bulk metal former. The system is analyzed with respect to accuracy and repeatability.

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