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Design and manufacture of closed die multi-axial forging tool

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Abstract. In the last decades many solutions were developed to achieve multi-axial forging. Outstanding among these is the two-way process that can be implemented on the Maxstrain unit of the Gleeble thermophysical simulator. Although the experiments performed on the Gleeble system were well suited for characterize mechanical models, this system had some serious issues, such as the outflow of material from the forging zone. To solve these problems, a new forming tool was designed, in which the total volume of the workpiece is deformed, and the shanks used for fastening can be omitted.

Keywords: multi-axial forging, design, material science, manufacture, testing, simulation

1 Introduction

In the last decades the production and testing of ultrafine grain materials has undergone a significant development [1, 2]. The average grain size of these materials is approx. 70-500 nm, which results in increased strength, higher fatigue resistance, increased toughness, superplasticity compared to conventional coarse-grained bulk materials [3, 4].

In most cases this particle structure is achieved by severe plastic deformation (SPD) in bulk materials. The coarse-grained, as received bulk material undergoes a structural transformation under high shear stress, which results in an ultrafine-grained state [5].

Several solutions have been developed for the practical implementation of this technology, like high pressure torsion, equal channel angular pressure, friction-assisted lateral extrusion, alternating extrusion-compression, or multi-axial forging [6-11]. Multi-axial forging stands out from the listed technologies with its easy toolability and implementation. It can be used to forge specimens up to 50-100 mm or even larger [12], that allows to step out of the usual size range of laboratory tests.

In previous studies, the MaxStrain unit of a Gleeble 3800 thermophysical simulator was used to physically implement the two-way multi-axial forging [13]. The equipment makes it possible to control the parameters of forging, such as load, tool movements and temperature, with high accuracy [14]. The only setback of this system is the fastening of the workpiece. The workpiece must have two relatively big stems, of which the volume is significantly larger compared to the volume of the deformation zone (figure 1).



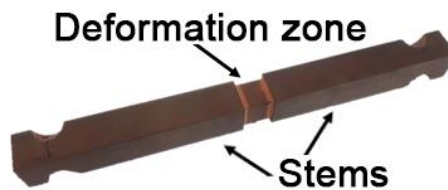


Figure 1. Gleeble specimen with a significantly smaller deformation zone in the middle compared to the size of the stems.

The size of the formed zone between the individual forming steps has showed a clear decrease, which was the result of a material flow during forging in the direction of the stems [15]. As a result, the forgeable volume of the specimen decreased with each forming steps, leading to a volume loss of approx. 25% during a 10-step forging cycle (figure 2).

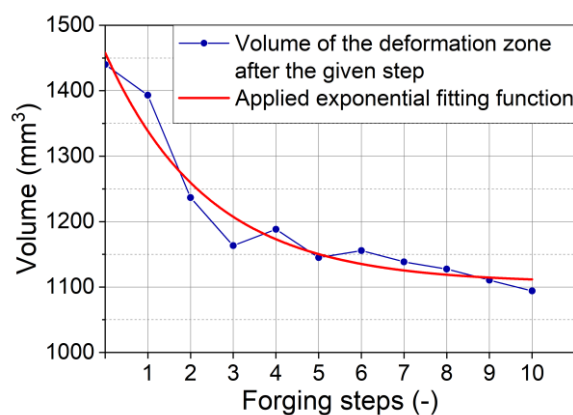


Figure 2. Volume change of the deformation zone after each forging step.

Due to such a decrease in the volume of the forged zone, a problem with reliability and general validity of the material properties determined by this technique arises. In order to eliminate this problem, we aimed to design and manufacture a new closed-die multi-axial forging tool, which can be used to study non-monotonic material behaviour.

2 Design and manufacture

2.1 Constructional considerations

At the beginning of the design process a list of requirements was made. The tool was designed for the already available MTS 810 universal material testing equipment, so the geometry of the tool as well as the maximum load capacity of the machine, which was 250 kN, had to be considered. Other aspects were the locking of the shafts, the centering of the specimen, the provision of manual or machine tool rotation, and ergonomic design in line with occupational safety considerations [16]. The mechanical properties of the CuE to be tested had to be taken into account to dimension certain parts of the tool.

To eliminate the material flow into the stems, the workpiece was modified so that its entire volume will be forged. To do this, a closed die cavity had to be created that could prevent the uncontrolled flow of volume in any directions.

2.2 Tool movements

In order not to have out the workpiece from the tool during a multi-step forging process, it is necessary to form two pairs of perpendicular tools. Thus, there is always an active, moving tool pair and a passive, fixed position tool pair for the given forming step. The tool pairs are bounded on two sides by flat closing

plates to form a 20mm×20mm×10mm tool cavity. The nominal dimensions of the specimen are 20mm×10mm×10mm.

During a forging step, the specimen is compressed parallel to its 20 mm side length so that the new nominal dimensions of the originally 20mm×10mm×10mm workpiece will be 10mm×20mm×10mm (figure 3). At the end of the given step, the stamps are pushed to their rear end position by means of the ejector pins, and then the side is locked by leaving the pins inside. By removing the ejectors from the passive tool pair of the previous step, the active and passive tool roles are swapped. Before starting the next step, the tool must be rotated by 90 °.

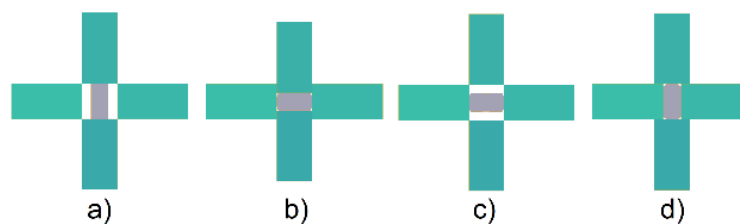


Figure 3. Initial state of a two-way forging cycle (a), final state of the first forging step (b), resetting of the tool position before the next step (c) and final state of the second forging step (d).
The workpiece is grey, and the tools are green.

2.3 Tool design

The tool can be divided into three main units. These are the center block, the linear actuators, and the tool housing (figure 4).

The tool housing provides a stable frame for the tool and ensures the uniform movements of the tools. The center block is where the specimen is forged, so its primary function is to position the stamps and to form a closed die cavity. The main function of the linear actuators is to move the stamps and to compensate any asymmetric movements by allowing the center block move.

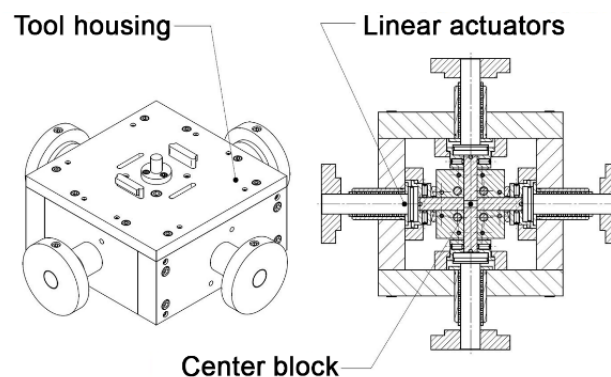


Figure 4. The main structural elements of the tool

If one of the two opposing tools moves faster relative to the other, the stamp holder will collide with the boundary ring. Since the boundary ring is attached to the tool housing, thus the entire tool moves with it and begins to pull over the stamp on the opposite direction. This way, when the end position is reached, the workpiece will always be in the centre.

2.4 Watts-Ford experiment

To size some components, the load force was estimated using QForm3D software. To improve the accuracy of the finite element simulation, we measured the planar deformation flow curve of the CuE

material to be tested later with the tool. To determine the flow curve Watts-Ford method was used [17]. The result of the measurement and the flow curve fitted to it are shown in figure 5.

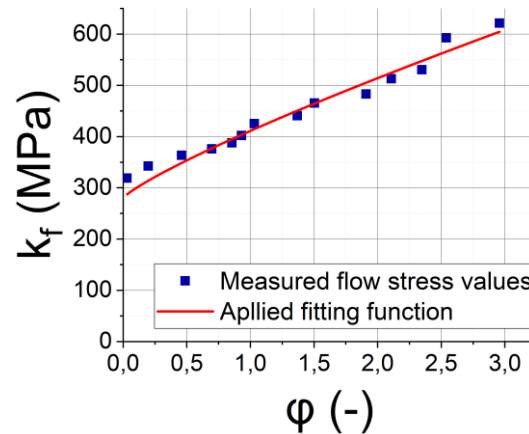


Figure 5. Flow curve obtained from Watts-Ford experiment

To determine the flow curve, a simplified Johnson-Cook equation was used. The effect of forming rate and temperature were negligible due to the nature of the Watts-Ford experiment [18]. The form of the function thus simplified is shown in Eq. 1.

$$k_f = C_0 + C_1 \cdot \varphi^n \quad (1)$$

The flow stress (k_f) for the given deformation (φ) was determined by fitting three parameters on the measured points (C_0, C_1, n), of which $C_0 = 280 \text{ MPa}$ is the yield strength of the material.

2.5 Finite element simulation

For the sizing of the components, a 3D finite element model was used to estimate subsequent tool loads. Although the forging process can be simplified to a 2D planar deformation problem, it could not provide the necessary information about the loads of the two planar plates closing the die cavity.

The flow curve determined during the Watts-Ford experiment allows to simulate the forging of the workpiece. Based on the simulation, the loading of the tools for four forging steps is shown in figure 6.

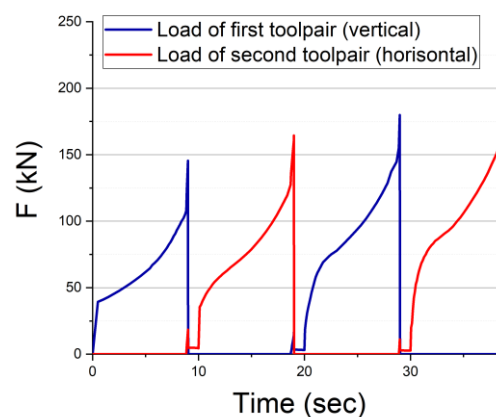


Figure 6. Tool load during finite element simulation of the first 4 forging steps

The force values shown in figure 6 increase drastically by the end of each individual forging steps. This is because tool movements were used as boundary conditions during the simulations instead of tool load. When the available space in tool cavity, which decreases with the tool movement, is almost zero, the workpiece can no longer deform substantially. This results in a nearly vertical jump in the force curves. Under real measuring conditions, however, this will not be a problem, as the forces in this way mark the end of the forming step, and then the operator stops the movement of the tools immediately.

It is also important to mention, that the applied material model assume a monotonous hardening material, although previous studies have shown that the load always decreases as a result of a change of direction during multi-axial forging [11], [13], [15]. Thus, the tool load will never reach the critical level.

2.6 Manufacturing

The tool must be able to move in multiple directions, which requires precise machining and assembly of the individual parts. The parts involved in the forging and guiding them must therefore be finalized in sub-assemblies after roughing. To avoid inaccuracies due to the friction of the tool movements, very strict form and position tolerances are required during production.

3 Results

The designed tool was manufactured and shown in figure 7. The tool fully complies with the requirements list.

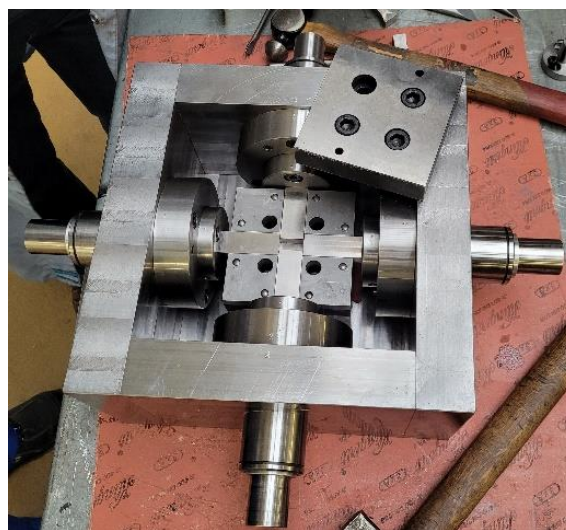


Figure 7. Finished multi-axial forging tool

4 Summary

Based on our knowledge of tools for multi-axial forging, a new, closed die cavity forging tool was designed. Its structural design eliminates the uncertainties arising from the volume loss of the previously used Gleeble system due to the deformation of the whole workpiece volume. The construction also allows to examine plane strain deformation on a larger range. During the experiments with this tool the cumulative plastic deformation can exceed 10. Measurements on a wide scale like this can help to better understand the mechanical properties and operating mechanisms of ultrafine grain materials.

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