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ONLINE VISIOPLASTICITY IN FORGING PROCESSES

MATTHIAS SCHMIDTCHEN, ANJA BRETHFELD, GUNTER LEHMANN

Technical University of Mining and Technology, Institute for Metal Forming, D- 09596 Freiberg,
Bernhard-von-Cotta-Straße 4, Germany
Corresponding Author: matthias.schmidtchen@imf.tu-freiberg.de

Abstract

In the present paper a contactless optical method for visioplastic investigation of the displacement and strain field in hammer forging was discussed. Coupled with thermographic measurements the visioplastic investigations were compared with numerical computations using the commercial FE - code *QForm*. Experiments were performed using stocks of initial dimensions 160 x 160 x 500 mm. For visioplastic investigation the surface was marked with a stud grid. Problems in the correlation process using the commercial software VEDDAC arising from this surface preparation were solved and discussed. The displacement field was used as indicator for damage sensitive regions.

Key words: Visioplasticity, correlation of grey scales, hammer forging, numerical simulation, crack initiation, micro crack

1. INTRODUCTION

In hammer forging the strain state is significantly affected by geometrical and frictional conditions in the contact zone between tool and material. Actual investigations were done in optimization of the tool geometry and the thermal – mechanical optimization of the forging processes. During hammer forging the initiation of surface cracks limits the maximum reduction and lowers the quality of the product. In the optimization process numerical computations are common. To control the accuracy of the results and to develop and evaluate appropriate damage models experimental investigations are necessary. Visioplasticity methods are used for evaluation of the complex strain states. On the other hand the method is restricted to slightly changing surfaces. In hot forming due to oxide scale growth and descaling processes the initial surface is completely removed. To avoid these problems an optical method (correlation of grey scales Michel et al. 1998 and Kieselstein et al. 1997) is combined with a surface marked with a stud grid. An optimization of the grid and the correlation technique is discussed below. On the base of these results experimental investigations were compared to numerical simulations using the commercial FE - code *Qform*. The objectives of these comparisons are the evaluation of the strain state and the damage model used.

2. OPTICAL VISIOPLASTICITY METHOD FOR HOT FORMING AND THEIR OPTIMIZATION

For online investigations of the displacement field the optical method of correlation of grey scales (Michel et al. 1998 and Kieselstein et al. 1997) was used. To investigate a displacement field, the distributions of grey values between two digitized pictures have to be compared. A commercial correlation based image processing algorithm (VEDDAC) was applied to determine a set of local pattern displacements between two object states. From these local investigations finally the whole in-plane displacement field is predicted.

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The maximum of the set of local cross correlation coefficients

$$C(i',j') = \frac{\sum_{i,j=1}^{n} A(i,j)\, B(i+i',j+j')}{\sqrt{\sum_{i.j=1}^{n} A^2(i.j)\cdot \sum_{i.j=1}^{n} B^2(i+i',j+j')}}$$

$$\text{with} \quad |i'|,|j'| \le \frac{N-n}{2} \qquad (1)$$

are taken as a measure for the pixel shift of a small image pattern with size n x n pixels. In eq. (1) A(i,j) and B(i,j) describe the grey values of a pixel (i,j) in the image picked up from object state A and B. Relative pixel addressing i´, j´ with regard to the search area is used in eq. (1). Maximum search is carried out within an interactively predefined neighbourhood (N xN pixels) of the original pattern in state 1 (Fig. 1). For online applications the images where taken from a video – camera. The measurement accuracy

$$\delta l = L\, n/M \qquad (2)$$

depends on the length of the field of view of the equipment L , the pattern area pixel size n and the number of pixels M along the image edge.

For large plastic deformations a point tracking technique was used. Therefore the whole displacement is subdivided into a series of images taken from intermediate states.

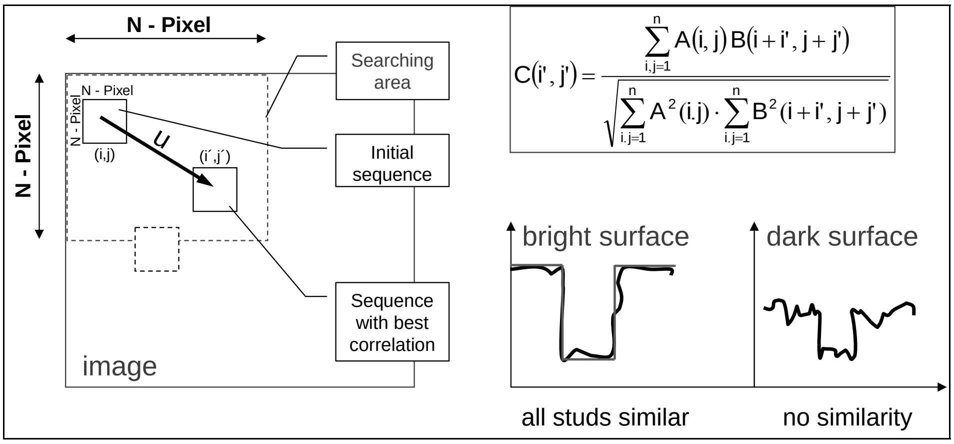

Fig. 1. *Search areas used for correlations and distribution of grey values around a stud for different intensities of radiation.*

The rapidly changing surface due the descaling process during forging will not allow optical displacement analyses. To get a stable surface structure the surface was marked with a stud grid (Fig. 1 –Fig. 3). In first upsetting test the measurement technique was optimized concerning stud thickness, length and density. The brightness necessary for an optimized analysis was also tested. The brightness of the images will affect the correlation process in large displacement analysis. As shown in Fig. 1 and Fig. 2 for similar studs the pattern around a stud will be completely different for a bright and a dark image (see small boxes within Fig. 2). In a bright image the surrounding of a stud will be the same value for the whole grid. Only pixels representing the stud itself are different. Thus choosing the wrong pattern size n x n and a displacement greater than the distance of the studs, wrong correlation results are computed. The algorithm is looking for the nearest point with the highest correlation coefficient. That is, for two similar points with the same correlation coefficient (e.g. due to accuracy of computation used), the point which is the nearest in relation to the original pattern position will be taken. This will be done even if it is the wrong one. Reduction in pattern image size or brightness of the image will give better results.

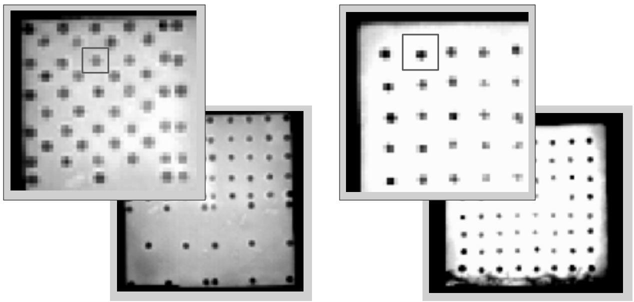

Fig. 2. *Comparison of the visibility of the studs using different brightness of the sample surfaces.*

Otherwise the stud geometry has to be optimized. From experimental investigations an optimum diameter of 3 mm and length of 15 mm using the same material for stud and base are found. The studs where clamped into 10 mm deep holes, drilled into the base material. The minimum distance between the studs is 5 mm (Fig. 3).

3. APPLICATION FOR ONLINE DETECTION OF SURFACE DEFECTS DURING HAMMER FORGING

In contrast to upsetting processes in hammer forging, regions with fixed material flow existing. In these regions inhomogeneities in the strain state also result in tensile stresses. Crack initiation occurs in these areas due to the dependence of formability on stress state. Critical areas are the surface and the core of a stock.

Optimization of the hammer forging process will concentrate on the maximum strain per stroke, tool shift and tool speed. The analysis and optimization of the hammer forging processes were done with a commercial FE - code *Qform*. To evaluate the numerical FE – model the optical visioplasticity method described above was used.

Experimental investigations where performed in cooperation with the Institut für Bildsame Formgebung at RWTH Aachen. For laboratory trials the surface of the stocks where marked with a stud grid (Fig. 3 and Fig. 4). The studs 3 mm in diameter and 15mm in length were produced at the Institute for Metal Forming, TU Freiberg. For studs and stocks (160 x 160 x 500 mm) equal materials were used (26NiCrMoV14.5). The studs were clamped in drilled holes (10 mm). Below the contact surface the distances of the studs are smaller than near the symmetry line. The trials were performed at a hydraulic press of RWTH Aachen.

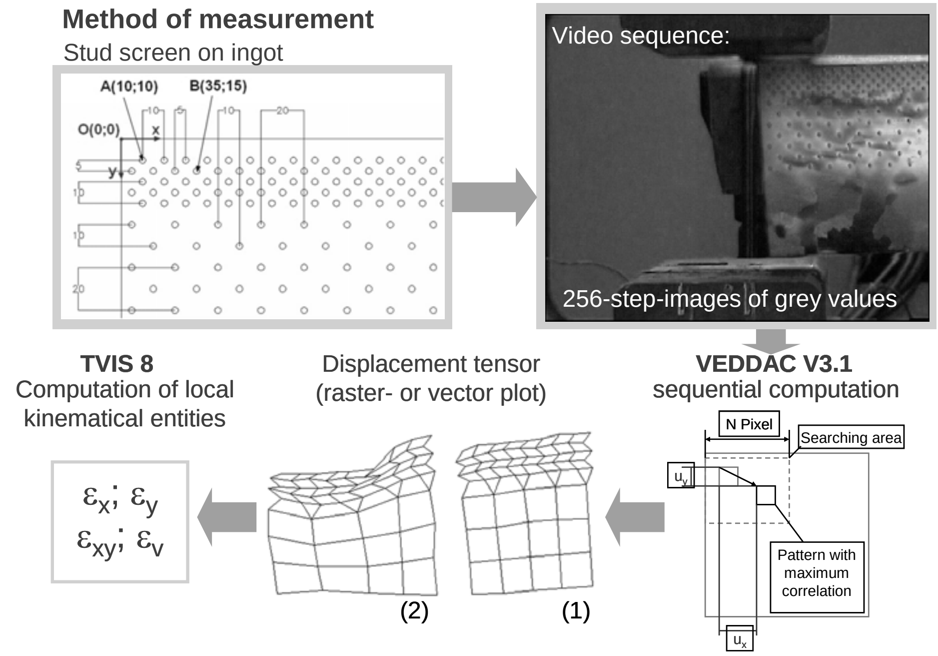

Fig. 3. *Method of visioplasticity measurements.*

After reheating up to 1200°C the stocks were cooled down in air to the critical temperature for crack initiation of approximately 850°C. The trials were performed with a tool 200 mm in length and 600 mm in width using different technologies. The results shown here were obtained with a technology of three strokes of $\varepsilon_{hi} = 30\%$, a tool shift of 60 mm and a tool speed of 70 mm/s.

For thermal and mechanical analysis the process was filmed by thermographic camera and video camera. Tool speed and force were measured at the same time. After recording the process sequences of images were analysed using the commercial correlation software VEDDAC V3.1 and the visioplasticity software TVIS 8 of Institute for Metal Forming of TU Freiberg to obtain the strain field.

The temperature development at the surface of stock 1 during forging is given in Fig. 5. Due to energy dissipation and descaling the measured surface temperature will rise. Displacement and strain field are shown in Fig. 6 and Fig. 7.

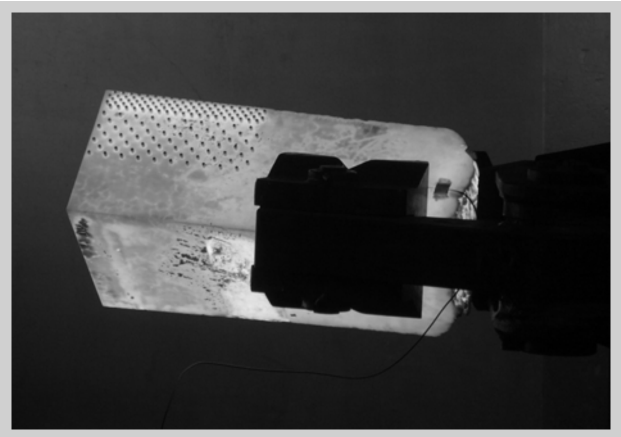

Fig. 4. *Stock marked with stud grid after reheating.*

4. COMPARISON OF VISIOPLASTICITY RESULTS AND COMPUTATION

The evaluation of the numerical model was performed using the displacement of a line of points below the tool and in the centre line of the stock (Fig. 7). Additionally the strain state at the surface was compared (Fig. 6). The final position of the selected points coincides with the displacement vector computed by cross correlation using equation (1). For simulation and experiment similar point tracking lines were obtained. Both, the strain state and the displacement field are in good agreement with experimental data. Thus regions with crack initiation can be identified in an early stage during forging.

In hammer forging of a stock maximum stresses are to be found near the edges of the saddle. For analysis purposes the first three strokes were investigated starting from the free end of the stock:

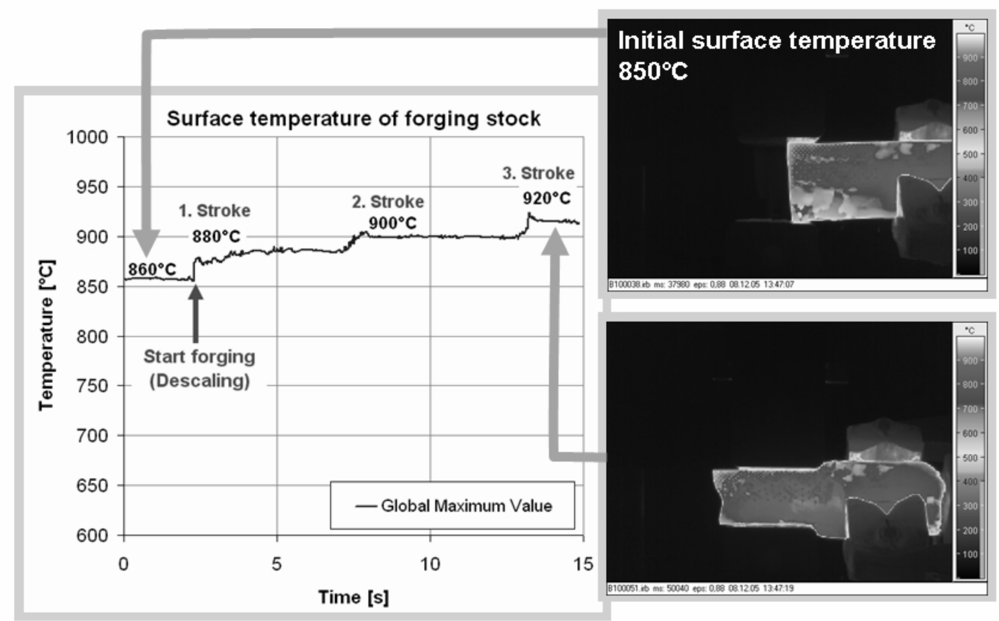

Fig. 5. Sketch of the changes in the mean surface temperature during forging measured with thermal camera (images on the right).

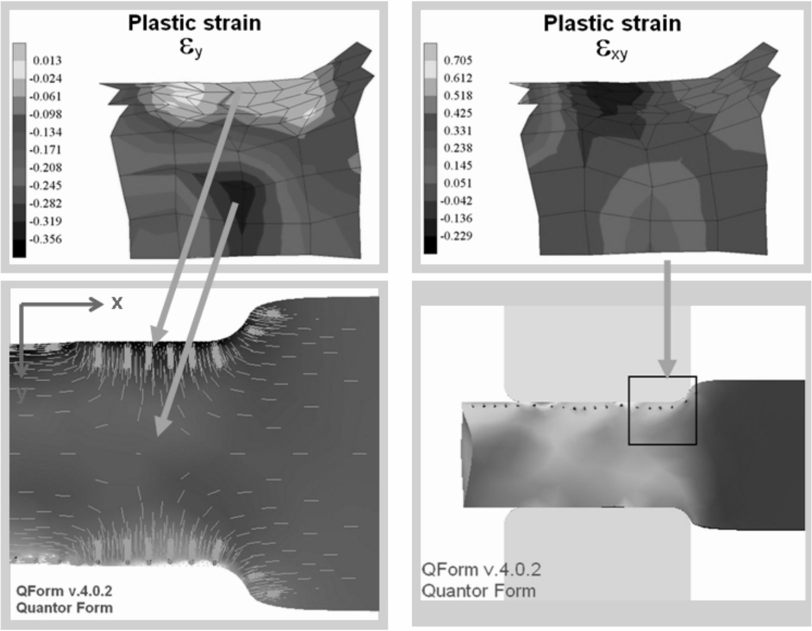

Fig. 6. Comparison of numerical simulation using Qform and experimental results.

1st stroke, upper region (Fig. 7a, d)

At the side surfaces of the stock the upper row of the stud grid and the row at the centre line were selected for point tracking.

Experiment and theory are showing three regions with different orientation of the displacement vector.

Region1 (Fig. 7a, studs 2-5, counted from left side): Due to frictional forces the displacement is orthogonal in relation to the contact surface with the tool. The material sticks to the tool and no displacement parallel to the contact surface will occur.

Region 2 (Fig. 7a, studs 6-7): In this region the contact conditions will change. Friction dominated material flow is also affected by material at the end of the forging region. Frictional effects become less dominant. Vertical displacements and thus tensile stresses occur. This region is sensitive to crack initiation.

Region 3 (studs 8-11): Frictional forces do not affect the material flow anymore. The choking zone bounds the material movement only.

2nd stroke, core region of the stock (Fig. 7c, f)

As shown in Fig. 7c, f the material movement will be separated in the core of the stock into two regions by a neutral line. The position of this line is in the first quarter of the contact length (stud 5 in Fig. 7c, f). From numerical simulation it is known that in this region high tensile stresses occur. In the core the first quarter of the contact length is thus also sensitive for damage.

2nd and 3rd stroke, contact region of the stock (Fig. 7b, e)

Additional to the damage sensitive region at the tool edge a second region occurs at the bounding line between the former stroke and the actual one (Fig. 7b, e, stud 1-3). Until the level of the former stroke is reached an additional neutral point can be seen. Thus beneath the tool cracking of the contact surface can also occur.

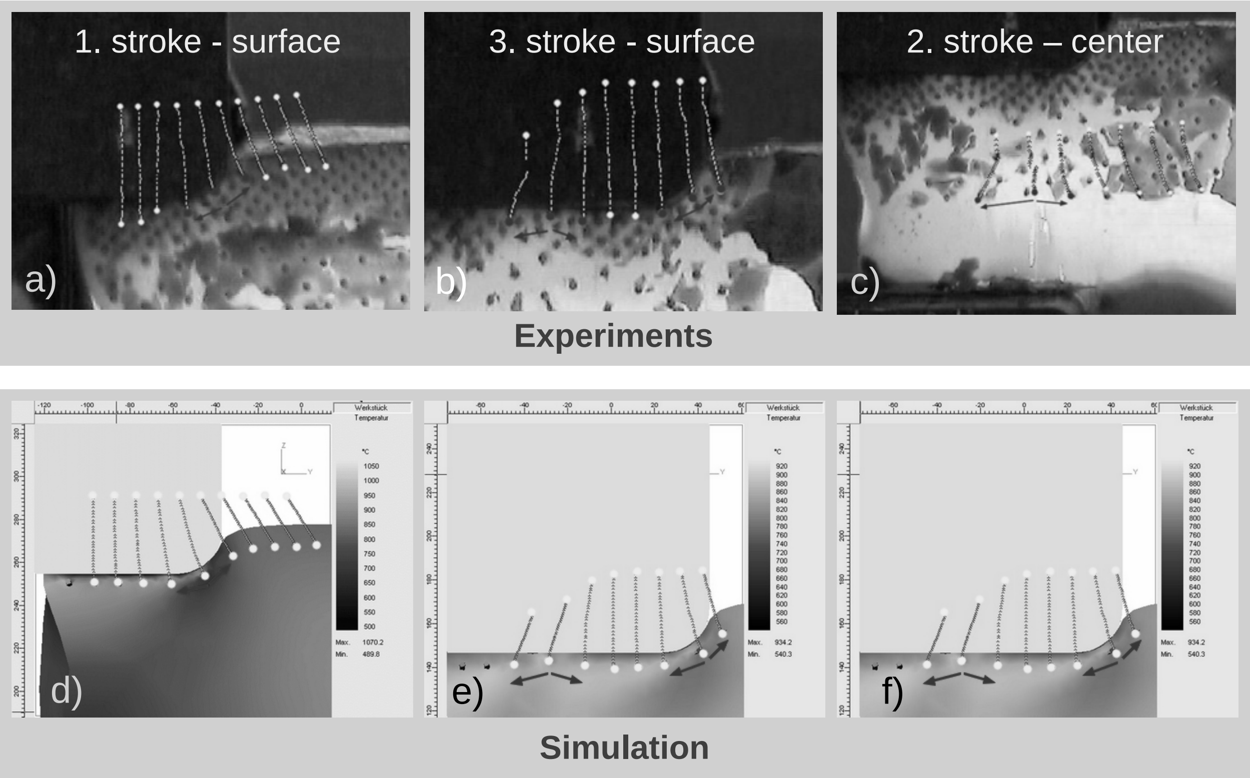

Fig. 7. Identification of regions with crack initiation (experimental and numerical).

Visioplasticity analysis will indicate an inhomogeneous deformation before macro cracks are visible. Therefore microstructural investigations were performed (Fig. 8). As shown in Fig. 8 micro cracks were found below the surface at the position computed by correlation and numerical simulation.

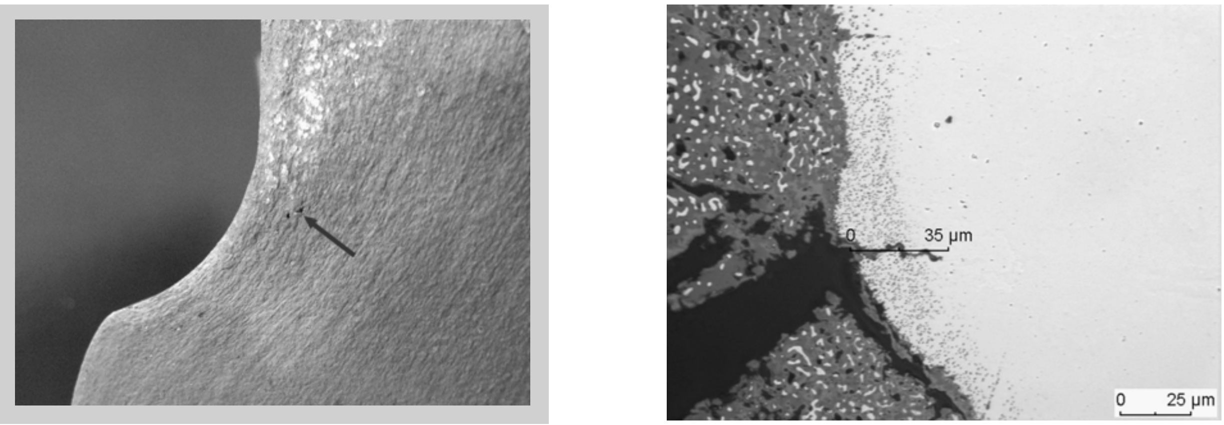

Fig. 8. Microstructural investigations of the crack initiation during the forging process after 30 % reduction at 850°C initial temperature (26NiCrMoV 14.5).

5. CONCLUSIONS

In the present paper a contactless optical method for visioplastic investigation of the displacement and strain field in hammer forging was discussed. Coupled with thermographic measurements the visioplastic investigations were compared with numerical computations using the commercial FE - code *QForm*. Experiments were performed using stocks of initial dimensions 160 x 160 x 500 mm. For visioplastic investigation the surface was marked with a stud grid. Problems in the correlation process using the commercial software VEDDAC arising from this surface preparation were solved and discussed. The displacement field was used as indicator for damage sensitive regions. Microstructural investigations confirm the results obtained by visioplasticity and simulation. In the first stroke crack sensitive regions occur at the front edge of the tool, while in the next strokes additional crack sensitive regions at the surface along the bounding line between the strokes were found. In the first quarter of the contact length in the centre of the stock a crack sensitive region was computed for all strokes performed.

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WIZJOPLASTYCZNOŚĆ ON-LINE W PROCESIE KUCIA

Streszczenie

Bezstykowa, optyczna metoda do badania wizjoplastycznego przemieszczeń i odkształceń w kuciu na młotach jest omówiona w artykule. Analiza wizjoplastyczna połączona z pomiarami termograficznymi jest porównana z wynikami obliczeń numerycznych prowadzonych w programie MES - *QForm*. Doświadczenia wykonano dla wsadu o wymiarach początkowych 160 x 160 x 500 mm. Dla badań wizjoplastycznych na powierzchni próbki naniesiono siatkę. Problemy z korelacją między poszczególnymi parametrami, wynikające z metody przygotowania powierzchni próbki, analizowano komercyjnym programme VEDDAC, co również omówiono w artykule. Pole przemieszczeń zostało wykorzystane jako wskaźnik oceny tendencji do pękania materiału.

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