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COMPOSITES

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MODELLING OF FORMING PROCESSES OF TWO-COMPONENT Al-Al ALLOY COMPOSITES

This paper analyses two-component material flow during forming processing. It is important to work out a suitable method of analysis of the flow of such materials during forming processing to improve the manufacturing technology of products with required shapes and properties. Physical and numerical simulation of the flow of PM preforms during forging was carried out to obtain qualitative information. The hot forming approach was adopted to obtain high density and required shape of PM composite products. Starting materials were obtained by cold pressing and hot consolidation; these were a layer and coat-core preform of aluminium and Al17Si5Fe3Cu1.1Mg0.6Zr powder. Flow of metal-metal composites during closed--die forging and extrusion is analysed. Starting materials were obtained by cold pressing and hot consolidation; these were a layer and coat-core preform of aluminium and Al17Si5Fe3Cu1.1Mg0.6Zr powder. Simulation of the flow of PM preforms during forming processes using the finite element simulation program LARSTRAN/Shape was carried out to obtain qualitative information. Numerical modelling required setting up procedures for input of initial material and identification of its constituents and their control during the shaping simulation and remeshing. To accomplish this, a workpiece consisting of several different materials was input to the finite element simulation program LARSTRAN/Shape. Results of numerical FEM simulation of the flow of PM preforms during forming processes by closed-die forging and extrusion are comparable to the observed zones of component materials.

Keywords: **light metal-metal composites, PM aluminium, FEM modeling, closed - die forging, extrusion**

MODELOWANIE PROCESU ODKSZTAŁCANIA DWUSKŁADNIKOWYCH KOMPOZYTÓW OTRZYMANYCH Z PROSZKÓW ALUMINIUM I STOPU ALUMINIUM

Odkształcanie na gorąco wyprasek z materiałów kompozytowych otrzymanych metodą metalurgii proszków stosuje się do wytwarzania wyrobów o dużej gęstości. W artykule przedstawiono analizę płynięcia materiałów kompozytowych metal--metal podczas odkształcania w procesie kucia w matrycach zamkniętych i wyciskania. Wypraski wielowarstwowe typu warstwa-warstwa i powłoka-rdzeń otrzymano przez prasowanie na zimno i zagęszczanie na gorąco. Do wytworzenia wyprasek zastosowano proszek aluminium i proszek jego stopu Al17Si5Fe3Cu1,1Mg0,6Zr. Numeryczne modelowanie odkształcania takich materiałów wymagało przygotowania procedury wprowadzania wyjściowych danych materiałowych, ich identyfikację i kontrolę podczas odkształcania oraz podczas generowania nowej siatki elementów. Wyrób złożony z wielu różnych materiałów oraz charakterystyki tych materiałów stanowią dane wyjściowe do symulacji metodą elementów skończonych z zastosowaniem programu LARSTRAN/Shape. Numeryczna symulacja płynięcia podczas odkształcania materiałów kompozytowych dała ilościowe i jakościowe informacje o zachowaniu się tych tworzyw podczas kucia lub wyciskania. Wyniki symulacji numerycznej są porównywalne z danymi eksperymentalnymi przedstawiającymi rozkład składników na przekroju wyrobów.

Słowa kluczowe: **lekkie metalowe materiały kompozytowe, proszki aluminium, modelowanie metodą elementów skończonych, kucie w matrycach zamkniętych, wyciskanie**

INTRODUCTION

Multilayer materials are a new generation of construction products and the PM route involving hot forming enables manufacture of high density products with required properties. This research focuses mainly on the material properties of the products. Layer-materials are a unique type of composite, formed from two distinct constituents, which exhibit graded composition, appearing to transform from one material to another, thus producing gradual changes in characteristics and offering new exploitable functional properties. Accordingly they extend the range of solutions for constructional components. Research to extend the development of these materials is directed mainly towards obtaining experimental data necessary for working out their optimum chemical composition, microstructure and properties [1, 2], and also developing methods to manufacture and processes semi and finished products by means of forging [2-5].

This paper analyses two-component material flow during forming processing. Starting materials were obtained by cold pressing and hot consolidation; these were a layer and coat-core preform of aluminium and Al17Si5Fe3Cu1.1Mg0.6Zr powder. Numerical simulation of the flow of PM preforms during forming processes by closed-die forging and extrusion was carried out to obtain qualitative information. Numerical modeling required setting up procedures for input of initial material and identification of its constituents and their control during the shaping simulation and remeshing. To accomplish this, a workpiece consisting of several different materials was input to the finite element simulation program LARSTRAN/Shape [6, 7].

The analysis of the flow of multilayer materials during extrusion is the aim of this paper. It is important to work out a suitable method of analysis of the flow of such materials during extrusion to improve the manufacturing technology of products with required shapes and properties.

MODELLING OF MULTI-COMPONENT MATERIALS

The possibility to model multi-component materials has been implemented in the Finite-Element simulation program LARSTRAN/Shape [6] and its Pre- and Postprocessing tool PEP [7]. It is possible to select the individual elements and assign them to a specific material. This new functionality required modifications in three steps of the modeling procedure:

– Preprocessing: Generation of the simulation model and its parameterisation,
– Solving: Computation of the modelled process,
– Postprocessing: Evaluation of the computed results.

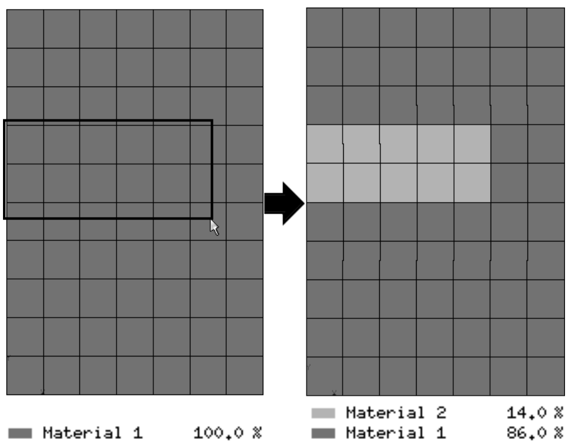

Fig. 1. Assigning different materials

Rys. 1. Zaznaczenie obszarów występowania materiałów

Preprocessing: A graphical user interface (GUI) was implemented to the Pre- and Postprocessor PEP to allow a simple and fast assignment of the different materials to the elements of the workpiece. Figure 1 shows a workpiece with two different materials being assigned to its elements. The database representing the simulation model was adopted in a manner that several material datasets could be opened at the same time.

These data sets describe the flow curves and the thermo-mechanical properties of the materials of the workpiece. The element database had to be changed to include an additional attribute, which stores the material data set assigned to each element (represented by a positive integer value). The number of different materials to be used simultaneously is not limited.

When starting a simulation, a file (the so-called input deck) is written containing all data necessary to describe the modelled process, including all materials of the workpiece. The assignment of the different materials to the elements is written in an assignment table. Figure 2 explains the principle of the assignment table.

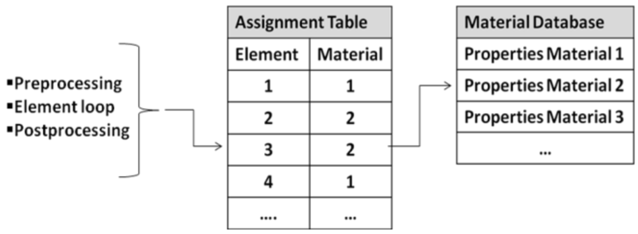

Fig. 2. Assignment Table

Rys. 2. Tabela przyporządkowania elementom własności materiałów

Solving: The implementation of the multi-component materials required two main modifications of the solver algorithm concerning:

– The generation of the stiffness matrix,
– The data transfer algorithm.

The stiffness matrix is generated during the element loop which requires the flow stress and the thermal properties for each element. The material to be used for the computation of the flow stress and the thermal properties for a certain element are read from the assignment table.

If a remeshing operation occurs, which is necessary during simulations of metal forming processes with large strains, the assignment table needs to be updated. The assignment table is stored for postprocessing (e.g. visualisation of the history of the distribution of the different materials).

The transfer of the assignment table was carried out to the data transfer algorithm, which is used to transfer the metal forming properties (e.g. temperature and strain) to the new mesh generated in the remeshing algorithm. In contrast to the metal forming properties, which are nodal values and can be interpolated, the material distribution is assigned element by element and cannot be interpolated. A new assignment table is generated by the following algorithm: The centre of gravity is computed for all elements, of the old as well as the new, mesh. In a loop for all elements of the new mesh, the nearest

centre of gravity of the old mesh is found. Then the material assigned to this element is adopted for the element of the new mesh.
Postprocessing: During the Postprocessing of the simulation, the distribution of the different materials in the workpiece can be visualised for each step of the simulation. This requires reading in the material assignments stored in the assignment tables saved during the simulation, together with the computed history of the metal forming properties (e.g. temperature, stresses and strains).

MODELLING OF TWO-LAYER COMPOSITES Al-Al ALLOY

Closed-die forging investigation

Physical modelling of closed-die. The flow of multi-layer composite material during closed-die forging was investigated on aluminium - Al17Si5Fe3Cu1.1Mg0.6Zr alloy, designed Al17. Metallic specimens were prepared as two-paraller layer and coat-core type. The preforms were made by hot consolidation of the powders. After heating at 550°C, the preforms were closed-die forged on a hydraulic press in the die (Fig. 3) heated to 500°C. Figure 4 shows the cross-sections of the forgings with noticeable changes during the flow of the material type coat-core in the die. Information about the flow of multi-component and multi-layer materials during forming are used to modify the algorithm of the LARSTRAN/ /Shape program.

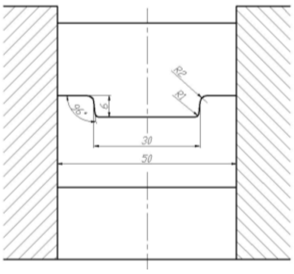

Fig. 3. Schematic of the shaping die
Rys. 3. Schemat matrycy kształtowej

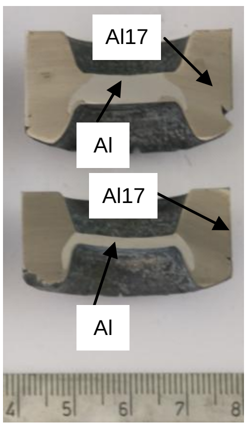

Fig. 4. Shape of the component materials in type coat Al17-core Al forging-cross section
Rys. 4. Kształt składników materiału na przekroju odkuwki typu powłoka Al17-rdzeń Al

Numerical modelling of closed-die forging of layer perform Al-Al17. The model of the die with the workpiece for the simulation is shown in Figure 5.

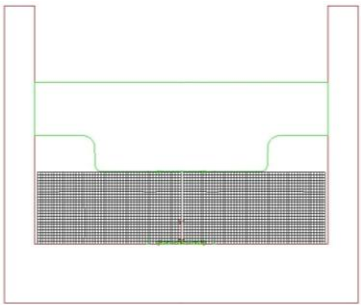

Fig. 5. Generated geometry of the tools and two component Al-Al17 specimen using PEP/LARSTRAN Shape
Rys. 5. Wygenerowana w programie PEP/Larstran Shape geometria narzędzi i dwuskładnikowego wsadu Al-Al17

The simulation was for two-layer and coat-core specimens made from aluminum RAl-1 and Al17 alloy. The stress - strain relationship for aluminium was defined by the Hensel-Spittel equation [8] and for Al17 alloy stress-strain relationships was taken from [9]. The boundry conditions for the die were: punch velocity - 1 mm/s, die temperature 500°C, friction coefficient 0.2, and material temperature 550°C. Figure 6 shows the simulated distribution of component materials for a cross-section of the forging obtained from a two-layer preforms. The distribution of strains (Fig. 7) confirm the good quality of the simulation results.

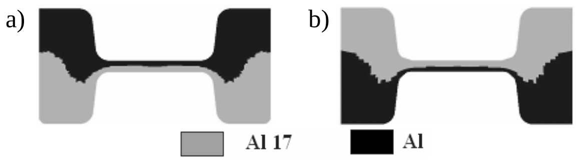

Fig. 6. Distribution of component in the two-layer materials on cross section of forgings: a) Al-Al17, b) Al17-Al
Rys. 6. Rozkład składników na przekroju odkuwki wykonanej z dwuwarstwowego materiału kompozytowego: a) Al-Al17, b) Al17-Al

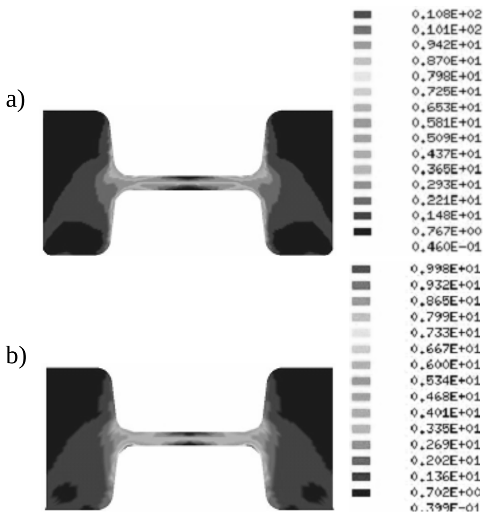

Fig. 7. Distribution of equivalent strain on a cross section of two-layer forgings: a) Al-Al17, b) Al17-Al
Rys. 7. Rozkład intensywności odkształcenia na przekroju odkuwki wykonanej z dwuwarstwowego materiału kompozytowego: a) Al-Al17, b) Al17-Al

The simulation results of closed-die forging of PM preform type coat-core are shown in Figures 8 and 9. Shapes of the materials are qualitatively comparable with the results obtained during forging metallic Al-Al17 PM preforms (Fig. 4).

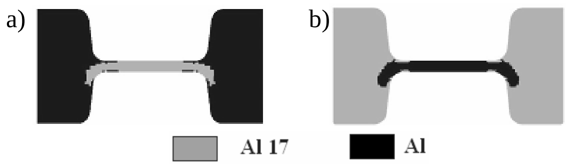

Fig. 8. Distribution of component materials on a cross section of forgings obtained from PM preform type coat-core: a) Al-Al17, b) Al17-Al

Rys. 8. Rozkład składników na przekroju odkuwki otrzymanej z przedkuwki typu powłoka-rdzeń: a) Al-Al17, b) Al17-Al

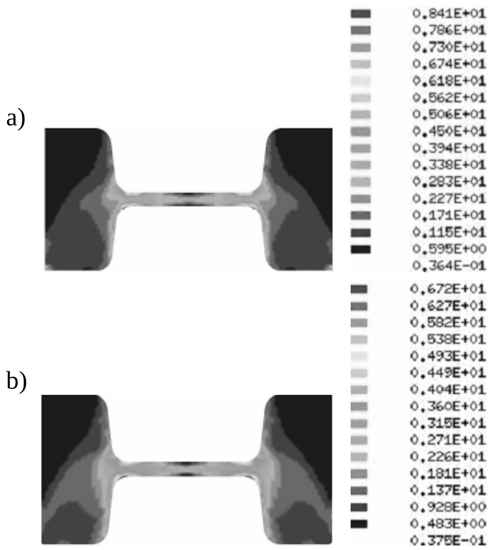

Fig. 9. Distribution of equivalent strain on a cross section of forging obtained from preform type coat-core: a) Al-Al17, b) Al17-Al

Rys. 9. Rozkład intensywności odkształcenia na przekroju odkuwki otrzymanej z przedkuwki typu powłoka-rdzeń: a) Al-Al17, b) Al17-Al

The distribution of the equivalent strain (Fig. 9) and component (Fig. 4) demonstrates the usefulness of the modified program for the analysis of flow of materials type coat-core.

Extrusion investigation of composites Al-Al17 alloy

The analysis of material flow during extrusion of multilayer and coat-core type performs starting with PM preforms was made.

Physical modelling of extrusion. Extrusion of two-layers preforms was carried out on the hydraulic press, using die angles of 90° and diameters of ϕ18 and ϕ10 mm to obtain products with extrusion ratios 4.11 and 13.32 respectively (Fig. 10).

The analysis of flow of preforms was carried out for hot densified, two-layer and coat-core type Al-Al17. Two-layer and coat-core type specimens had a diameter of ϕ = 35 mm and height respectively to extrusion ratios of 4.11 and 13.32. The specimens, two-paraller layer and coat-core type, were made by hot consolidation of the powders. These comprised a layer consisting of aluminium and aluminium alloy powders. Extrusion of preforms, heated to 480°C, was carried out on a hydraulic press, using die angle of 90° and diameters of 18 and 10 mm, to obtain products with extrusion ratio 4.11 and 13.32 respectively. The extruded specimens are shown in Figure 11.

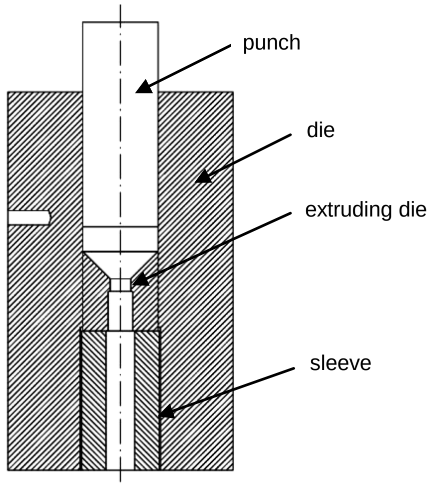

Fig. 10. Tools for the extrusion

Rys. 10. Narzędzia do wyciskania

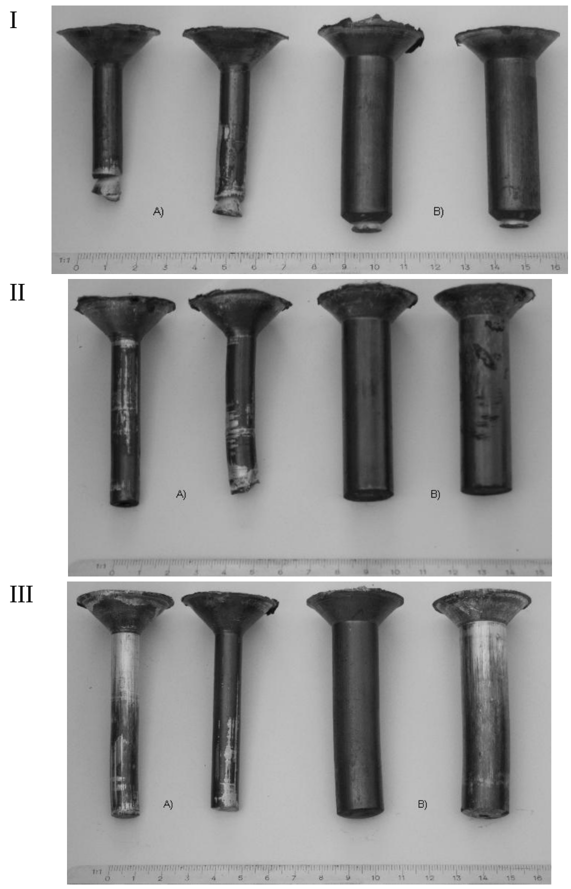

Fig. 11. Extruded products type coat-core: I - Al1-Al, II - Al-Al17 and type two-layer III: Al17-Al after extrusion with ratio: A) λ = 13.32, B) λ = 4.11 at 480°C

Rys. 11. Wyroby wyciskane typu powłoka-rdzeń: I - Al17-Al, II - Al-Al17 i dwuwarstwowe III: Al17-Al po wyciskaniu w 480°C ze współczynnikiem: A) λ = 13,32, B) λ = 4,11

Simulation of the flow PM coat-core material during extrusion. The simulation of extrusion was for coat-core specimens of alumnium RAl-1 and Al17 alloy. The stress--strain relationship for aluminium was defined by the Hensel-Spittel equation [8] and for Al17 alloy stress--strain relationships was taken from [9]. The boundary conditions for the die were: punch velocity - 1 mm/s, die temperature 480°C, friction coefficient 0.2, and material temperature 480°C. Figure 12 shows the distribution of component materials on cross-section of the extruded products obtained from coat-core preforms. Shapes of the zones of simulated materials are qualitatively comparable with the results obtained during extrusion of metallic Al-Al17 PM preform. The distribution of materials confirms the good quality of the simulation results.

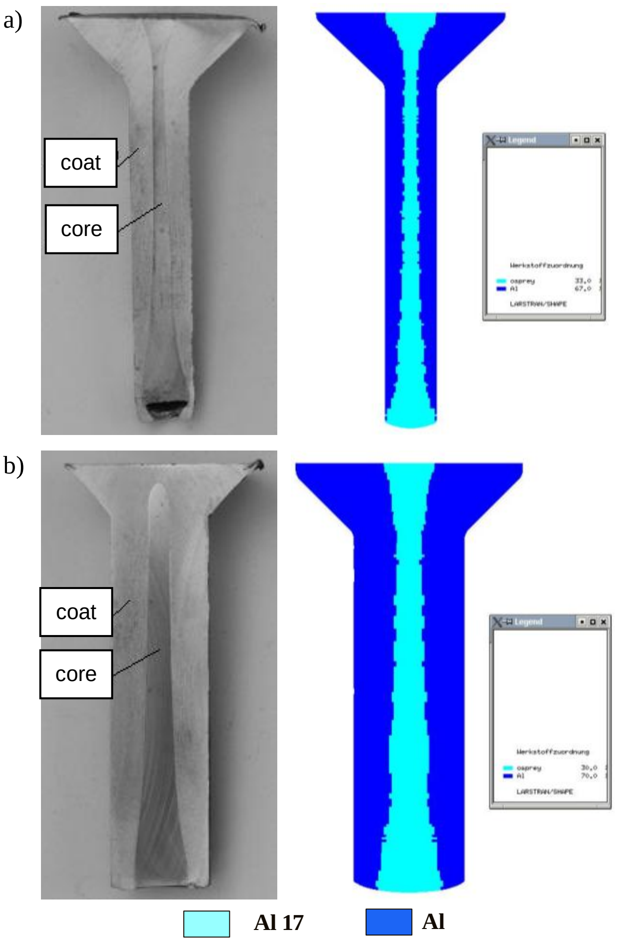

Fig. 12. Macrostructure in coat-core Al-Al17 performs and simulated distribution of component materials on longitudinal section of extruded products with extrusion ratio: a) 13.32 and b) 4.11

Rys. 12. Makrostruktura w wyciskanych próbkach i rozkład składników materiałowych otrzymany w wyniku symulacji wyciskania ze współczynnikiem: a) 13,32, b) 4,11

CONCLUSIONS

The physical modeling and simulation results show their applicability for the analysis of flow component of layer and coat-core composite materials during shaping. Procedures were developed for the assignment of the initial distribution of different materials in one workpiece and identification of its constituents, as well as their control during the shaping simulation and remeshing. A composites workpiece consisting of several different materials is the input to the finite element simulation program LARSTRAN/Shape. During pre-processing, the material assignment to be used during the simulation is performed by the element of the workpiece.

The flow of the material compounds during closed-die forging of coat-core performs, observed in the cross sections of forgings composed from two-layer material aluminium-Al17 alloy, is comparable with the simulation results. Experimental results pertaining to the flow of the material compounds during extrusion, observed in the sections of specimens composed from a coat-core material Al-Al17, are comparable with the simulation results.

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REFERENCES

[1] Neubrand A., Rödel J., Gradient Materials,: an Overview of a Novel Concept, Zeitschrift für Metallkunde 1997, 88, 358--371.

[2] Kiebeck B., Meyer-Olbersleben F., Bautaile mit kontraren Eigenschaften aus Gradientenwerkstoffen herstellbar, Maschinenemarkt 1999, 105, 38-40.

[3] Raβach S., Lehnert W., Simulation of the Deformation of Graded Materials, Advanced Engineering Materials 2000, 2, 442-444.

[4] Szczepanik S., Raβbach S., Hot forming of aluminium based gradient materials, Proc. ESAFORM the 5th International Conference on Material Forming, Kraków April 14-17, 2002, eds. M. Pietrzyk, Z. Mitura, J. Kaczmar, Publishing House Akapit, Kraków 2002, 335-338.

[5] Szczepanik S., Gradient Materials on Aluminium Alloy Basis Obtained from Powders, Inżynieria Materiałowa 2007, 3-4, maj-sierpień, 602-605.

[6] Diez R., Hindelang U., Kurz A., Revised form of LARSTRAN 80 documentation, LASSO Ingenieurgesellschaft 1996.

[7] Franzke M., PEP Programmer's Environment for Pre-/Post-processing - Handbuch zur Version 3.30, Institut für Bildsame Formgebung, RWTH, Aachen 2001.

[8] Hensel A., Spittel T., Kraft und Arbeitsbedarf bildsamer Formgebungsverfahren, VEB Deutsche Verlag für Grundstoffindustrie, Leipzig 1978.

[9] Szczepanik S., Przeróbka plastyczna materiałów spiekanych z proszków i kompozytów, AGH Uczelniane Wydawnictwo Naukowo-Dydaktyczne, Kraków 2003.

