ENGINEERING TRANSACTIONS • *Engng. Trans.* • **47**, 3–4, 351–367, 1999
Polish Academy of Sciences • Institute of Fundamental Technological Research
10.24423/engtrans.637.1999

EXTRUSION OF CuZn39Pb2 ALLOY BY THE KOBO METHOD (¹)

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Design of intelligent technologies based on the structural criterion is intended both to reduce the work of plastic deformation and to generate advantageous structure and mechanical parameters of metallic products. It enables external control of the deformation mechanism oriented towards time-spatial organization of the slip and localization of plastic flow in the transgranular shear bands. One of the industrial solutions presented in the paper refers to the production of rods of lead brass by the KOBO method, consisting in a complex extrusion of the ingot on a press with reversibly rotating die. The performed experimental investigations and their analysis comprised the mechanical aspects of the new, energy-saving technology of metal working and were concentrated on the evaluation of the possibility of formation of the final structure and by that means, of the expected mechanical properties of the products.

1. INTRODUCTION

Both the new and the conventional metallic materials, widely applied in production technology, are subjected to plastic working or thermomechanical treatment in order to give the products the desired shape and definite functional qualities. Unfortunately, the technologies of plastic working of metals and alloys, exploited at present, are energy-consuming, and the inadequate knowledge of the effect of external factors on the mechanism of plastic flow, considerably restricts the possibility of controlling the structure and the mechanical properties of the products.

(¹) Paper presented at the 2nd Seminar "Integrated Study on the Foundations of Plastic Deformation of Metals", at Dąbrówki (near Łańcut, Poland) Nov. 16 – 19, 1998.

On the other hand, it is known, that plastic flow of metallic materials subjected to large strain is accompanied by a diametrical change of the deformation mechanism from a homogeneous into heterogeneous one [1 – 4]. Then the following rapid destabilization of the dislocation substructure and time - spatial organization of slip leads to transgranular, localized plastic flow in non-crystallographic shear bands which, as a consequence, induces strain softening of metals and alloys [5 – 7].

A very significant experimental evidence concerns the change of the externally induced state of stress (loading scheme). It has been found that, irrespectively of the advancement of the deformation process, it leads each time to the localization of plastic flow, together with the occurrence of strong mechanical effects [8]. However, a single change in the loading scheme does not guarantee the maintenance of the state of the substructure destabilization while the deformation is continued. Hence, in order to retain the advantageous conditions of plastic forming of the materials, a repeated external interference is required. It should be noted that, as far as the phenomenon itself of the substructure destabilization requires an instantaneously greater deformation energy, the propagation of the shear bands, not only through numerous grains, but through the entire material, is accomplished at a considerable decrease of this energy in relation to its value from the period directly preceding the destabilization. Limitation of the strain hardening of metals and alloys is thus evidently connected with the necessity of a permanent domination of active shear bands.

The position of shear bands in relation to the respective direction of metal straining depends on the kind of the process and it varies from 35° for rolling up to 60 – 70° in the extrusion process. Also for this reason, the thickness or the diameter of the metallic element undergoing deformation has a significant influence on the extent of the interaction of the shear bands, and in that way on the magnitude of the relaxed volume of the material.

The main objective of the study is the presentation of a new, advanced technology of plastic working (the KOBO method), which has been verified under industrial production conditions during high-temperature extrusion of lead brass rods on a press with reversibly rotating die. Besides the analysis of the load parameters of the new and conventional processes, structural and mechanical investigations of rods obtained at various temperatures, have been carried out.

2. STRAIN LOCALIZATION. STRUCTURAL AND MECHANICAL ASPECTS OF THE PHENOMENON

The results of experimental investigations have definitely confirmed that strain localization in the shear bands is of universal character, and irrespectively

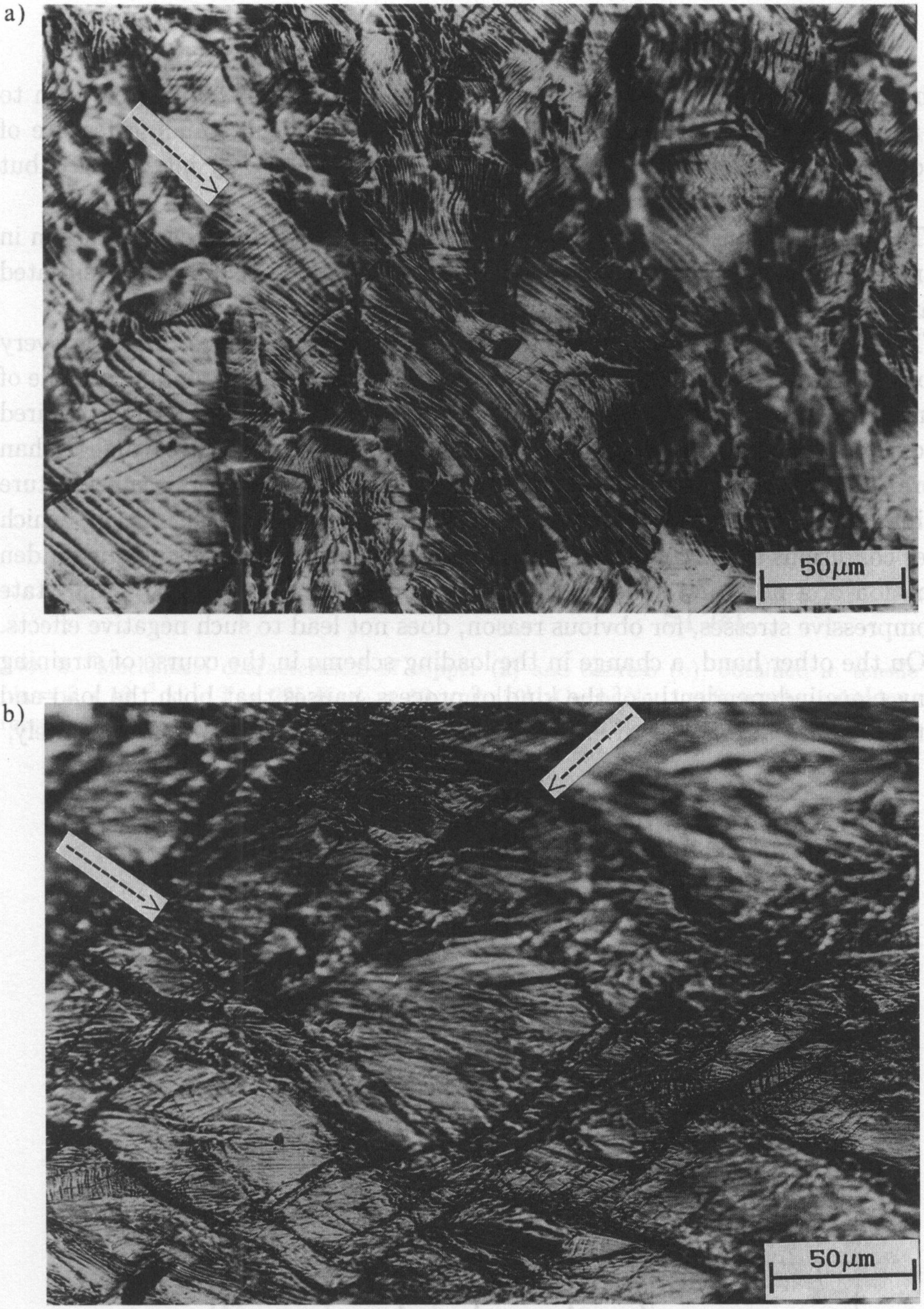


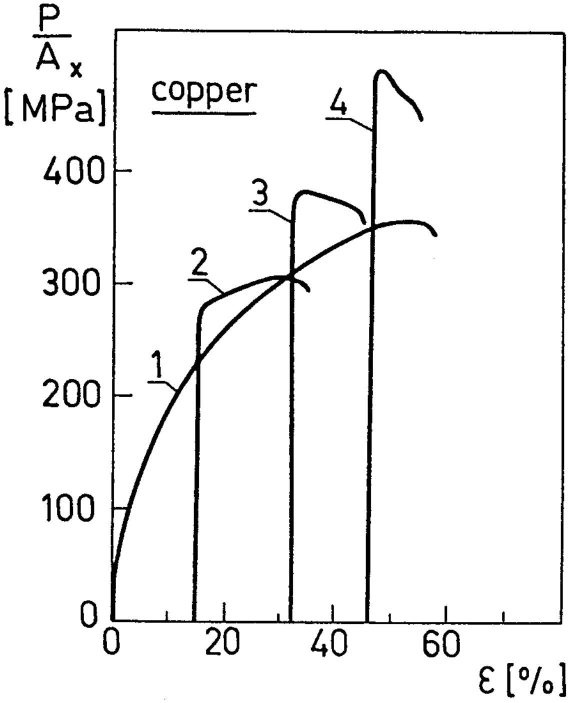
FIG. 1. Shear bands in α-brass with the grain size of about 50 μm, revealed in topological investigations; a – one family of shear bands generated during monotonic rolling with 45% strain, b – two families of shear bands formed as a result of rolling with 35% total strain (15% preliminary rolling and 20% cross-rolling).

of the scheme of the process, it comprises metallic materials subjected both to low as well to high temperature deformation [7, 9]. An outstanding feature of the discussed phenomenon is that it may be induced not only intrinsically, but also as a result of external actions.

The external constraints dependent on the mode of strain accommodation in the material decide whether one or a number of families of differently situated shear bands will be activated (Fig. 1).

The mechanical consequences of strain localization in the shear bands are very serious, although differentiated. Especially, if the change in the loading scheme of the material takes place after its unloading, the load and also the energy required to continue the process under new circumstances are considerably higher than before (Fig. 2). The resulting drastic evolution (destabilization) of substructure leading to plastic flow in the shear bands undergoes great acceleration, which under conditions of uni-axial state of tensile stress may be responsible for sudden formation of a neck and subsequent destruction of the material. Tri-axial state of compressive stresses, for obvious reason, does not lead to such negative effects.

On the other hand, a change in the loading scheme in the course of straining taking place independently of the kind of process, causes that both the load and the total deformation work are considerably lowered [9] (Fig. 3). Unfortunately,



[FIG.2 a)]

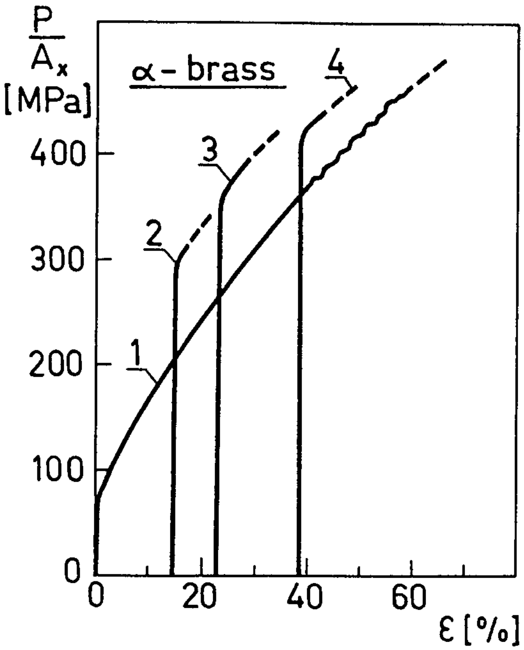
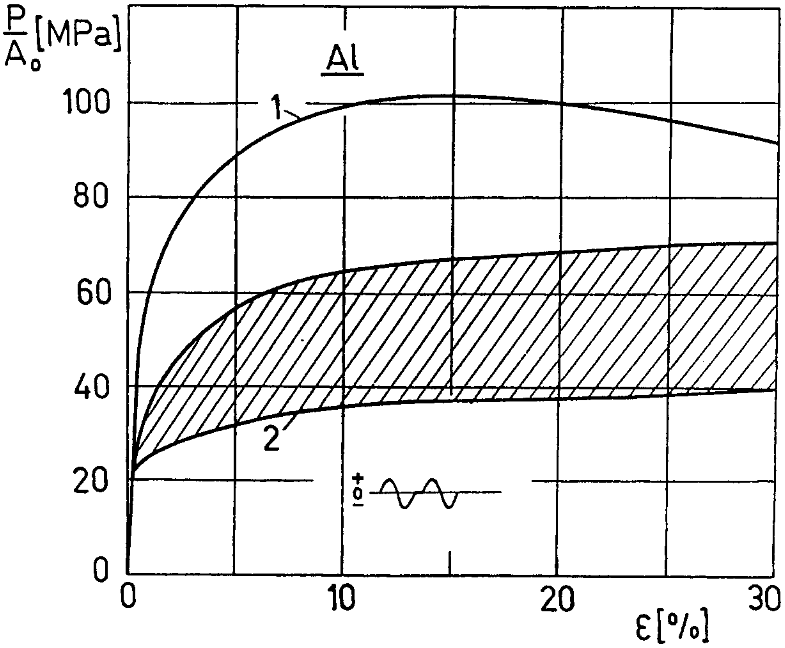


FIG. 2. Mechanical characteristics of copper (a) and α-brass (b), obtained in tensile tests ($\dot{\varepsilon}_0 = 5 \times 10^{-3}$ s^{-1}, $T = 295$ K, $d_0 = 50$ µm) [10]. Curve No. 1 reflects the behavior of the recrystallized material, while curves Nos. 2-4 – the behavior after preliminary rolling. The direction of tension was consistent with rolling direction.



[FIG. 3 a)]

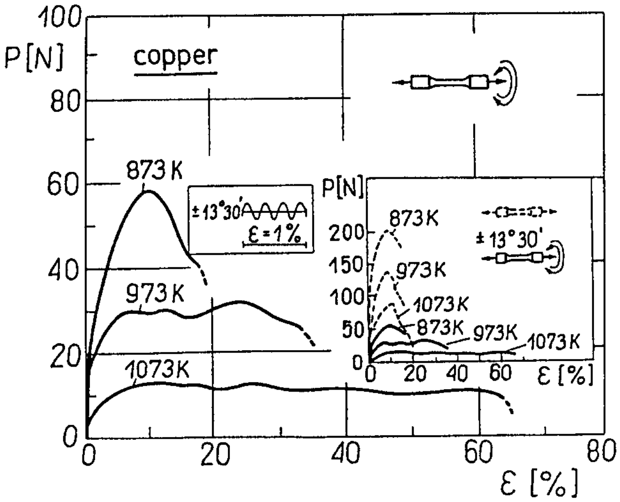


FIG. 3. Mechanical characteristics of aluminum (a) and copper (b). Aluminum with the grain size 70 μm, ($A_0 = 7$ mm^2) was deformed at $T = 295$ K, $\dot{\varepsilon}_0 = 8 \times 10^{-3}$ s^{-1}, $\dot{\gamma} = 0.4$ s^{-1} and $\omega = \pm 15°$ ($A_0 = 12.5$ mm^2); relation No. 1 describes a tensile test, while the hatched area No. 2 corresponds to data obtained in a complex tension with torsion [11]. Copper, with the grain size $\sim$ 15 μm, was deformed at various temperatures in tensile tests ($\dot{\varepsilon} = 4 \times 10^{-4}$ s^{-1}) with reversible torsion (continuous curves) and – for comparison – in simple tensile tests (dashed curves) [12].

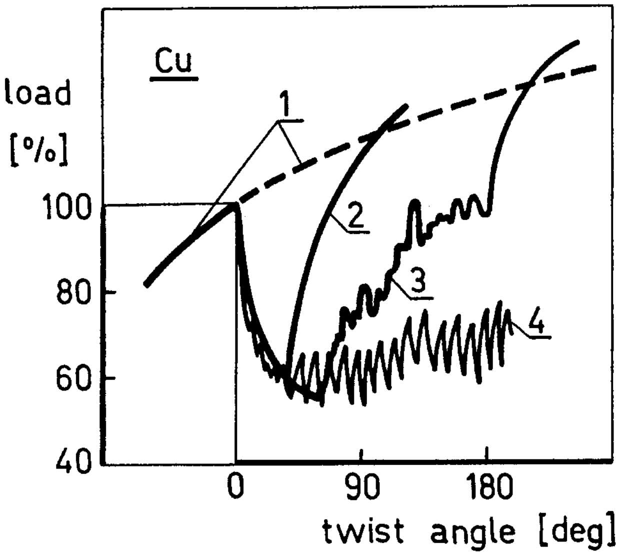


FIG. 4. Schematic presentation of a fragment of the relation between the tensile load and the torsion angle of a copper sample with the grain size $\sim$ 50μm, deformed at room temperature [8]. The gauge length and the diameter of the samples were 25 mm and 4 mm, respectively. Curve No. 1 represents simple tension, while curves Nos. 2-4 illustrate complex tension with torsion. Curve No. 2, in particular, represents unilateral continuous torsion by the angle 45°, curve No. 3 – by 180°, while curve No. 4 describes reversible cyclic torsion by the angle ±10°.

such a state does not last long, since after the new conditions of the plastic flow of the material have been established, the load parameters of the process increase to the previous level. If, however, the loading scheme is permanently subjected to essential changes, the deformation process may proceed in an energy-saving mode [9, 11] (Fig. 4).

3. PROCEDURE

Ingots of CuZn39Pb2 alloy with the diameter 135 mm were heated to the temperature 820°C and afterwards part of them were cooled to the temperature 770°C. Next all the ingots were subjected to direct extrusion on a press with the maximum pressure 7.1 MN at a rate 30 mm/s.

Two extrusion schemes were applied. Some of the ingots were deformed in the conventional mode, while the other were subjected to extrusion protected by a patent claim [12, 13] (the KOBO method) with a reversibly rotating die (Fig. 5) by an angle ±8° at the frequency 8 Hz. In this way, applying different variants of the process (loading scheme and temperature), 4 types of rods of 20 mm diameter were produced, allowed to cool in air, and next subjected to observations by means of optical and transmission electron microscopes, and to tensile tests.

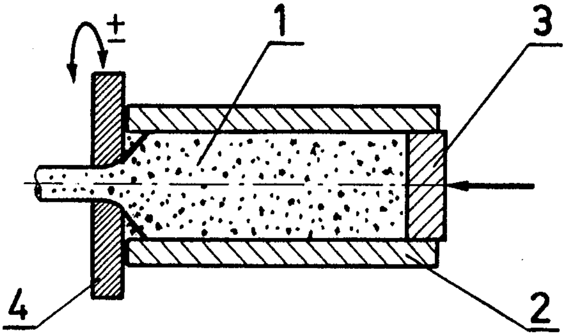


FIG. 5. Scheme of extrusion by the KOBO method on a press with reversibly rotating die: 1 – ingot, 2 – container, 3 – punch, 4 – rotating die.

4. ANALYSIS OF THE INVESTIGATION RESULTS

One essential information obtained as a result of the performed investigations concerns the load parameters of the extrusion process by the KOBO method. Generation of an energy-saving deformation mechanism through the application of a complex extrusion of a lead brass ingot on a press with reversibly rotating die, leads to more than 40% drop of the pressure (load) of the punch (Fig. 6). Such a result may by found to be surprising even in the context of the expected mechanical reaction. From the structural point of view, the induced (by the applied procedure) localization of strain in the shear bands does not require the activation of the accommodating secondary slips to preserve the cohesion of the material, thereby not leading to strain hardening. Although at high temperatures the processes of structural recovery proceed intensively, yet in the case of a homogeneous deformation mechanism connected with a multi-system, fine slip, this process takes place at a certain level of the stress flow, considerably higher than that required for deformation realized in the shear bands [14].

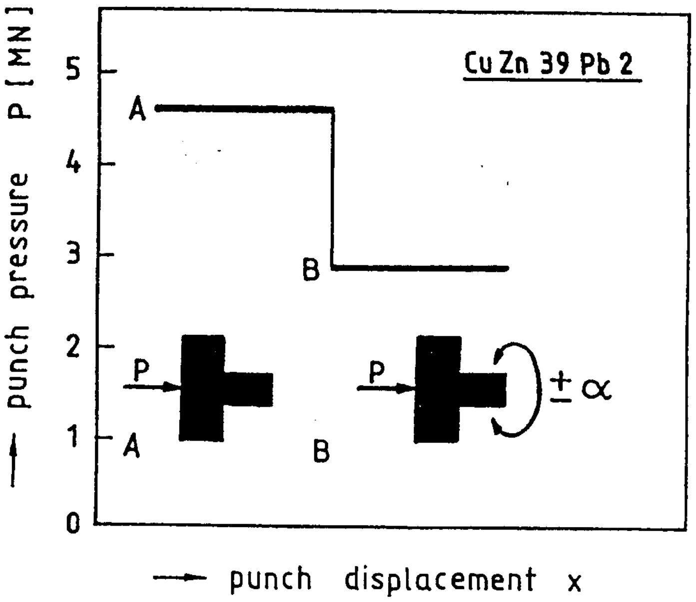
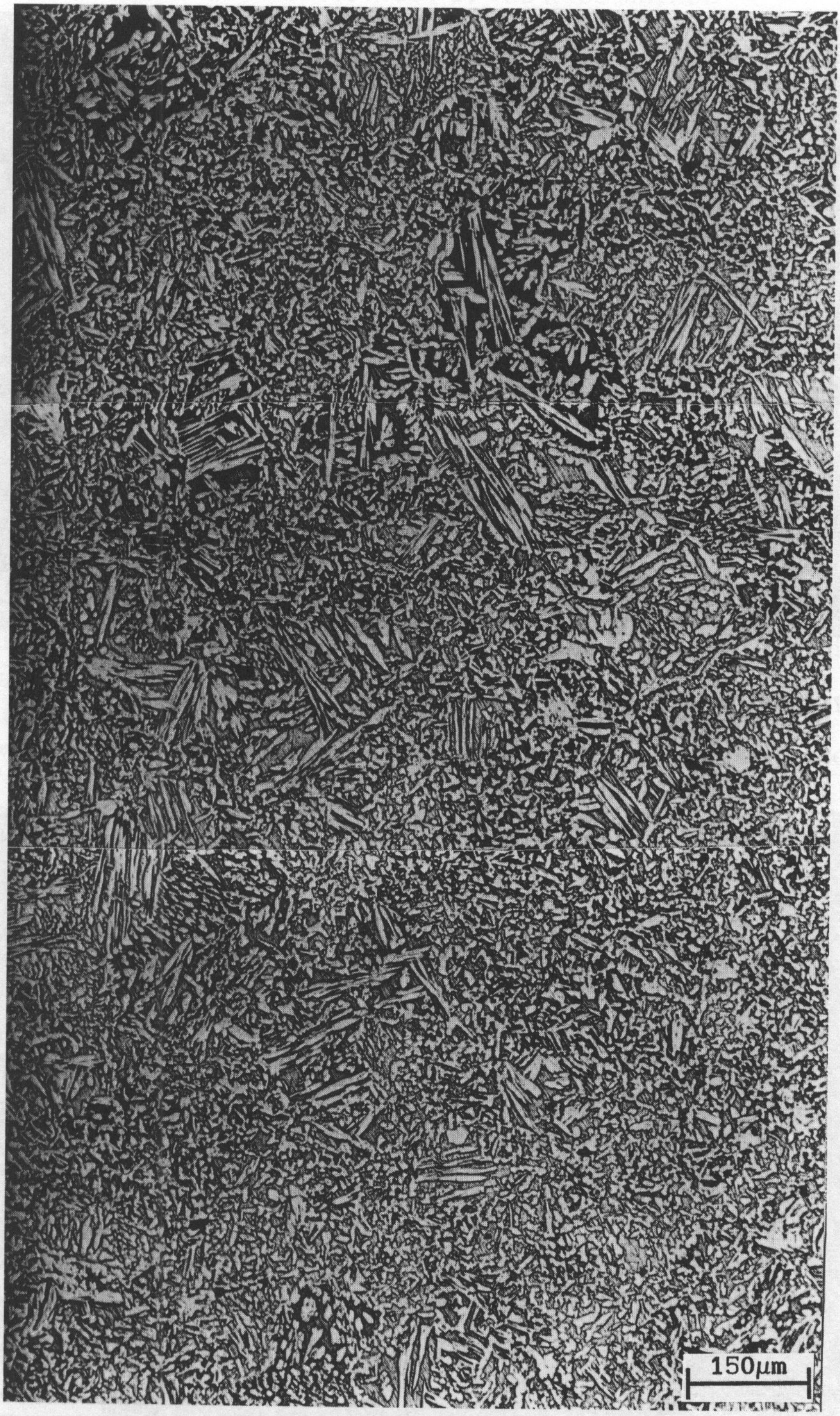


FIG. 6. Change in the pressure (load) of the punch resulting a change in the mode of extrusion of CuZn39Pb2 alloy; (T = 820 °C, v = 30 mm/s, λ = 45.6); A – conventional process, B – extrusion with reversibly rotating die.

During extrusion, as the heat is passing to the container, the ingot is allowed to cool. On the other hand, in the case when the initial temperature of the CuZn39Pb2 alloy is high, it can be deformed under the conditions of occurrence of the β phase only. In the process of a complex extrusion with a reversibly rotating die, the domination of the deformation mechanism in the localized form of shear bands is very strong. If the time required for a rod extrusion in this way to cool to the temperature of phase transformation $\beta \to \alpha + \beta$ is to short for the occurrence of recrystallization, the products of the phase transformation become a)



[FIG. 7 a)]

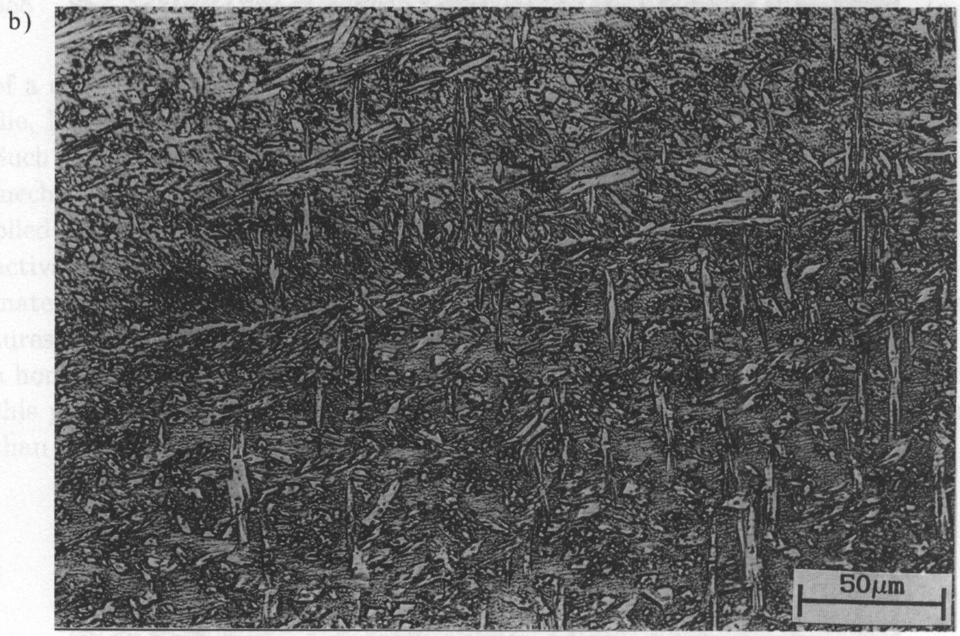


FIG. 7. Spatial organization of α and β phases in a rod extruded from CuZn39Pb2 ingot at temperature 820°C on a press with reversibly rotating die.

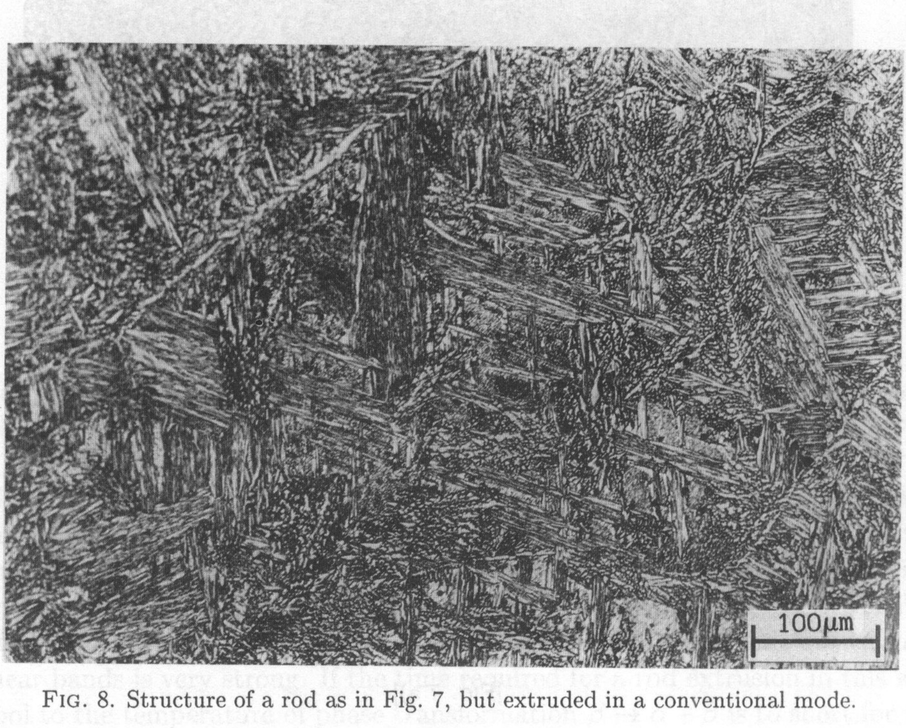


FIG. 8. Structure of a rod as in Fig. 7, but extruded in a conventional mode.

situated along the transgranular shear bands forming a pseudo - composite [15] (Fig. 7). Such a structure definitely differrs from the observed random distribution of the particular phases in rods extruded at the same temperature but in the conventional mode (Fig. 8).

The situation changes when a lead brass ingot is deformed at lower temperature (770°C), and the structure is formed by a mixture of the phases $\alpha + \beta$. Independently of the mode of extrusion, a characteristic feature of the rod structure is its fibrous character, which is manifested in the form of "small chains" of the α phase particles, oriented in agreement with the rod axis (Fig. 9). The microstructure of the alloy revealed as a result of electron-microscopic observations is also very similar in both cases (Fig. 10), with the β phase demonstrating morphological features associated with bainitic transformation [16]. When basing exclusively on the structural investigations, it is practically impossible to distinguish between rods obtained at the temperature 770°C by way of conventional extrusion and rods produced in the complex extrusion process with a reversibly rotating die. It is not possible, either, to estimate unambiguously the role of recrystallization. In either case, besides strongly developed interphase boundaries, coagulation of the particular phases can be observed.

The tensile tests conducted for all rods have proved to be a much more sensitive method of estimating the structural differentiation. Examples of the tensile curves for an alloy extruded at various temperatures in a complex mode of plastic forming of rods are shown in Fig. 11. Table 1 contains the values of the proof stress (Y_s), ultimate tensile strength (UTS) and elongation (A) determined from these curves, additionally supplemented with data obtained for conventionally produced rods.

From the presented experimental data it follows that the complex mode of extrusion with torsion increases the strength properties of lead brass rods, while retaining their high plasticity. In particular, on account of the UTS value all rods extruded in that way can be classified as the semi-hard state ($\mathrm{UTS}_{\min}$ = 410 MPa), although their elongation meets the requirements set for the recrystallized state ($A_{\min}$ = 25%) or the extruded state ($A_{\min}$ = 20%), depending on the temperature of the process.

Table 1. Mechanical properties of rods of CuZn39Pb2 alloy.

Production method	Temperature of the process [°C]	Y_s [MPa]	UTS [MPa]	A [%]
Conventional extrusion	770 820	193.0 158.0	368.2 342.1	32.0 43.1
Extrusion with torsion (the KOBO method)	770 820	218.8 145.4	470.0 441.5	21.7 35.6

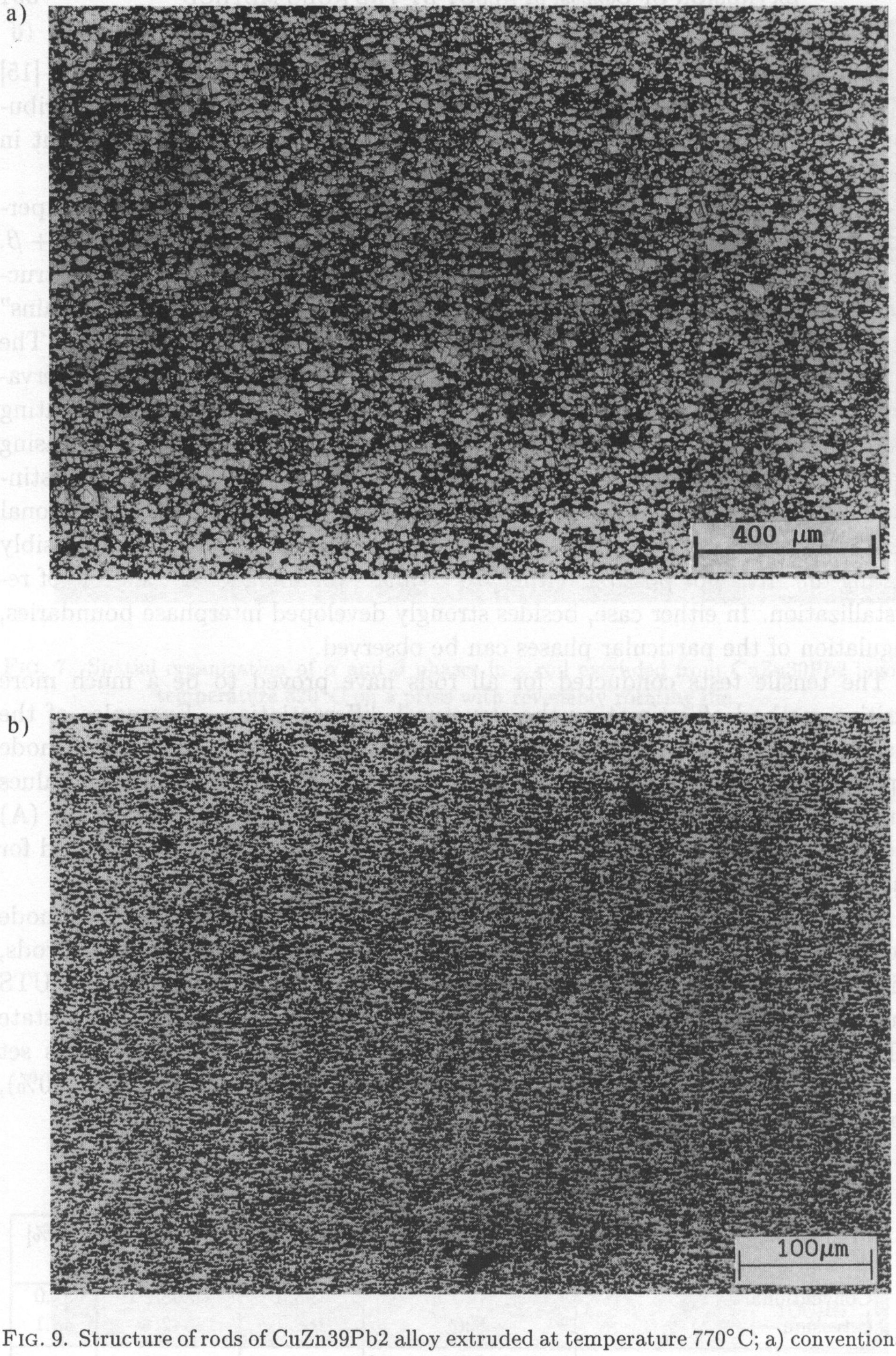
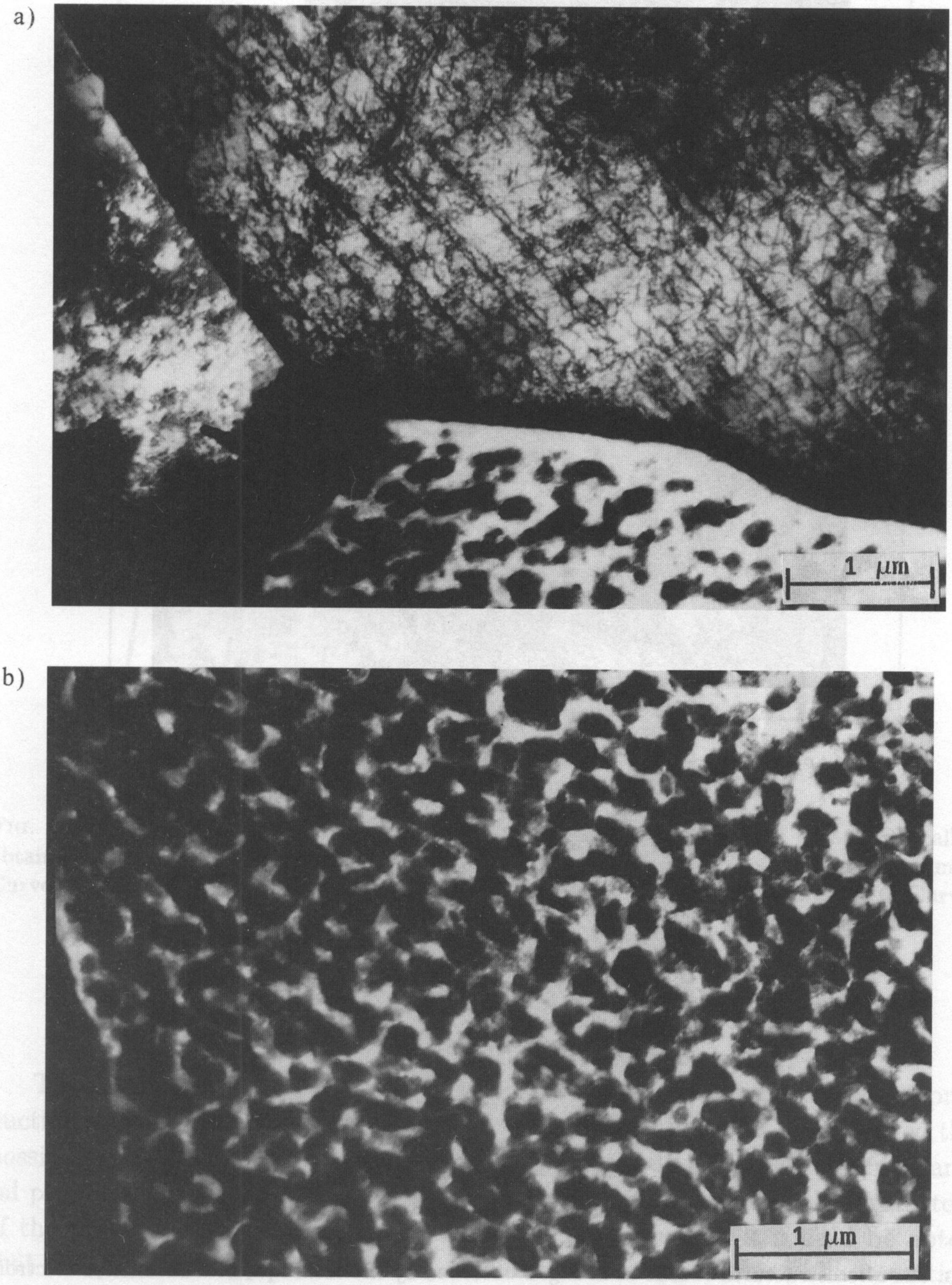


FIG. 9. Structure of rods of CuZn39Pb2 alloy extruded at temperature 770° C; a) conventionally, b) by KOBO method.



[FIG. 10 a), b)]

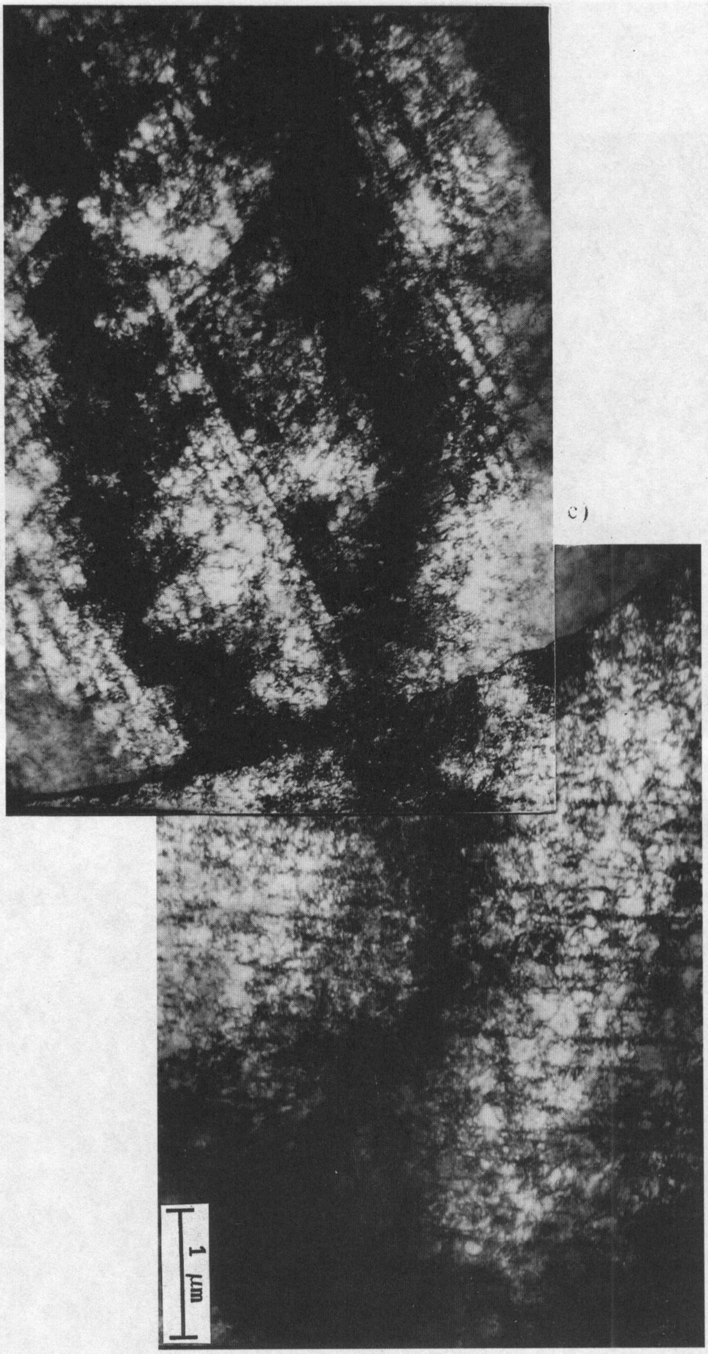


FIG. 10. Microstructures of rods as in Fig. 9 observed by the technique of transmission electron microscopy; a)– sample from an alloy extruded conventionally, b)– and c) – samples obtained by way of extrusion with reversibly rotating die (KOBO method).

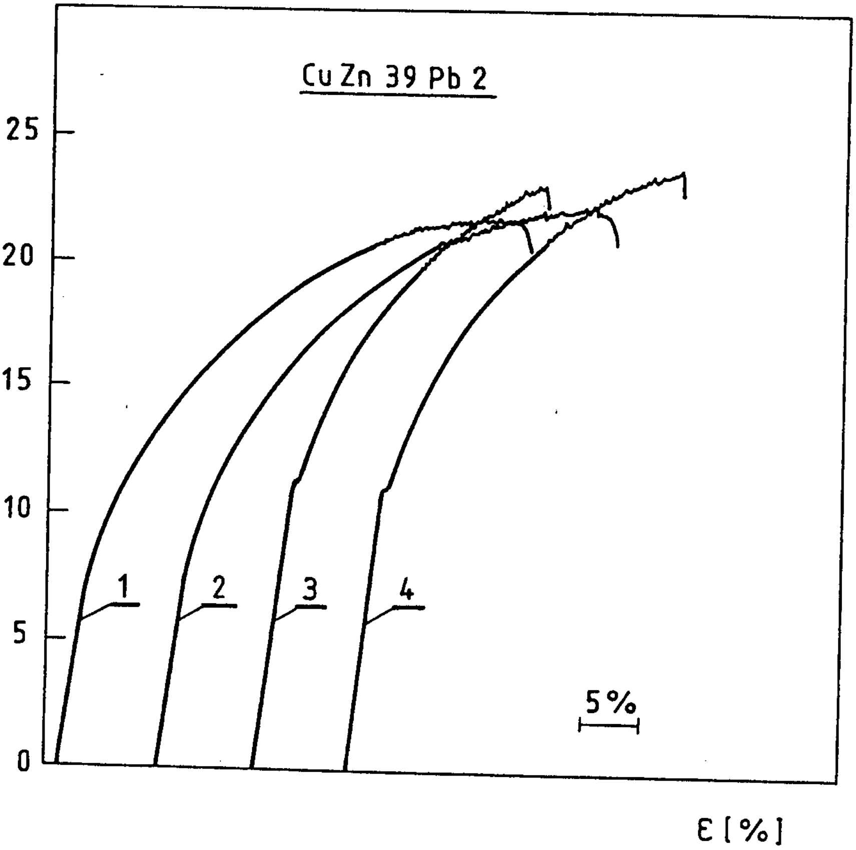


FIG. 11. Relations between the tensile load and elongation for samples of CuZn39Pb2 alloy obtained as a result of extrusion with reversibly rotating die ($\dot{\varepsilon}_0 = 2\times10^{-4}$ s^{-1}, $A_0 = 50.3$ mm^2). Curves Nos. 1 and 2 describe rods obtained from ingots heated to the temperature 820° C. Curves Nos. 3 and 4 were obtained during a process proceeding at the temperature 770° C.

5. CONCLUSIONS

The results of investigations of lead brass rods obtained under industrial production conditions in a complex process of extrusion with torsion, have proved the possibility of controlling the final structure and consequently, also the mechanical properties of the products. Considering the much lower strength parameters of the process when compared with conventional extrusion, it should be noted that the practical application of the new, structural approach to the operation of plastic forming of metallic materials, realized by the KOBO method, satisfies all the requirements set for highly advanced technologies and finds no world-wide equivalent.

ACKNOWLEDGEMENTS

The work received financial support from the Committee of Scientific Research (Poland) under project No. 7T08B 05 696/3145 in the years 1997–1998.

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Received February 8, 1999.