# HOT TORSION TESTS OF CARTRIDGE BRASS MS70

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# KRUTOVÉ SKÚŠKY MOSADZE MS70 ZA TEPLA

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**Abstrakt**

Nábojnicovú mosadz predstavuje hlbokoťažná mosadz označovaná ako Ms70 (podľa DIN noriem CuZn30). Klasická technológia výroby mosadzných nábojníc využíva ako vstupný polotovar valcované mosadzné pásy. Neustály tlak na výrobné náklady vyvolal technologickú zmenu, ktorá zaviedla výrobu mosadzných nábojníc z tyčí. Mosadzné tyče sú vyrábané prietlačným lisovaním za tepla a následným ťahaním za studena. Vo výrobe mosadzných Ms70 tyčí ako problematická operácia sa ukázal proces prietlačného lisovania za tepla. Preto bolo uskutočnené zisťovanie plastických vlastností za tepla prostredníctvom torznej plastometrie na univerzálnom plastometri SETARAM-VITKOVICE. Pre stanovenie možností dosahovaných rýchlostí deformácie boli odskúšané dva rozmery skúšobných tyčiek. Ďalej bola uskutočnená analýza vzťahov pre výpočet deformácie pri krutovej skúške a ich porovnanie. Boli porovnané štyri výpočtové vzťahy. Pre teplotu tvárnenia 850 °C boli uskutočnené vstupné krutové skúšky na vzorkách, ktoré boli odobrané z tyčí vyrobených z nábojnicovej mosadze. Skúšky krutom boli uskutočnené na skúšobných tyčkách krátkych a tiež dlhých. Univerzálny plastometer bol napojený na riadiaci osobný počítač. Počas samotných skúšok krútením boli sledované a zaznamenávané nasledovné hodnoty: časová základňa, krútiaci moment, osová sila, rýchlosť krútenia, počet skrútení do lomu a priebeh teploty tvárnenia. Vstupné skúšky krutom na nábojnicovej mosadzi umožnili stanoviť experimentálny plán pre reálny proces prietlačného lisovania nábojnicovej mosadze. Prvé skúšky krutom za tepla potvrdili, že u mosadze Ms70 nastáva po určitej deformácii dynamická rekryštalizácia. Rozhodujúcimi parametrami je teplota tvárnenia a rýchlosť deformácie z ktorej je odvodená rýchlosť prietlačného lisovania.

**Abstract**

Cartridge brass is represented by deep-drawing brass marked as Ms70 (CuZn30 according to DIN standards). Classical brass cartridge manufacturing technology uses rolled brass sheets as input semiproduct. Continuous pressure on manufacturing costs caused technological change which has introduced the manufacture of brass cartridges from bars. Brass bars are manufactured by hot extrusion pressing and subsequent cold drawing. The hot extrusion pressing process resulted to be a problematic operation in the brass bars Ms70 manufacturing. Therefore, the assessment of hot formability properties on universal plastometer SETARAM-VITKOVICE was realized. To determine the strain rates possibilities in a required range, two sizes of sample bars were examined. Furthermore, analysis of relations for calculation of the deformation during torsion test and their comparison were performed. Four computational relations were compared. Preliminary torsion tests were performed on samples taken from bars of cartridge brass Ms70. Temperature of formability was 850 °C. Torsion tests were carried out on long as well as on short sample bars. Plastometer was connected to control personal computer. The values of time, torque, tension force, speed of torsion, number of twists till rupture, and formability temperature behavior were recorded during torsion tests. Input torsion tests on cartridge brass enabled to determine experimental plan for the real process of extrusion pressing. The first results from torsion tests proved that brass Ms70 has significant effect of dynamic recrystallization after some deformation. Temperature of forming and the strain rate from which the extrusion press rate is derived are dominant parameters.

**Keywords:** brass, cartridge brass, hot formability properties, hot extrusion pressing, strain rate

## 1. Introduction

The manufacture of infantry ammunition begins with entry semiproducts with the shape of cups. From the material point of view we deal with deep-drawing brass Ms70 (70 % Cu and 30 % Zn), especially suitable for cold forming. The brass is marked as CuZn30 according to DIN standards. The manufacture of brass cups is realized from sheets which are hot rolled and subsequently calibrated on required thickness. Roundels corresponding to the weight of cups are cut from the strip, thus leaving waste after the cutting which has decisive influence upon material spending. Competition between cartridge manufacturers makes pressure on the lowering of costs. Brass cups manufacture from rolled sheets came to the stage when the further lowering of costs had not brought desired results [1]. The question of costs was solved by technological change which was introduced to the brass cup manufacturing from brass bars Ms70. The principle of changed technology lies in the fact that extrusion is cut out from the bar, whereas the weight of extrusion corresponds to the weight of cup. The new method is no-waste technology [2]. Although ammunition industry has solved the material costs, the problem has been shifted to the suppliers of brass bars Ms70, that is to metallurgical works. Bars of brass Ms70 with defined properties according to the demands of cartridge manufacturers were not commonly guaranteed. There were no difficulties with melting and casting in metallurgical works because they have casted blocks for hot rolling. It meant only the change in the shape of ingots to cast billets of cylindrical shape. Casted billets are cut to required length which enter extrusion press, where are extrusion pressing. During the adoption of manufacturing process, just extrusion pressing showed to be critical operation regarding the hot formability of brass Ms70, see [3] and [4]. Practical tests showed that the speed of deformation has the dominant influence on the quality of acquired brass Ms70 extrusion. Since further industrial tests were too expensive to be performed, the resolution of hot formability problem was transfered to laboratory. Laboratory experiments were carried out at universal torsion plastometer SETARAM-VITKOVICE in the company MATERIÁLOVÝ A METALURGICKÝ VÝZKUM s.r.o. Ostrava-Vítkovice [5].

The wide scale of plastometers which work on different principles is used for dynamical experiments and establishing of mechanical properties at different speeds of deformation and temperatures. Cam plastometer, torsion plastometer, pendulum plastometer and impact plastometer are the most used plastometers. Detailed information is listed in [6]. Torsion test using torsion plastometer is the most used test of plasticity nowadays. The used sample is defined by diameter **D** and length **L**. The sizes of used samples for torsion test on the plastometer SETARAM-VITKOVICE in the company MATERIÁLOVÝ A METALURGICKÝ VÝZKUM Ostrava-Vítkovice are listed in **Fig. 1**. In the particular case, there are two types of bar samples D x L = 6 x 50 mm and D x L =6 x 10 mm [7] and [8]. Torsion test is realized in the way that one end of the bar is fixed and the other end is subjected to torsion. Sensor of torque $\mathbf{T}_k$ is placed on the fixed end of the bar. By twisting, the sample bar tries to be reduced in longitudinal direction. Therefore, axial tension force in the sample originates as a result of the experiment. The mentioned plastometer enables to measure axial force **F**. There is directly incorporated the heating of sample on adjusted temperature in the device. Heating of the sample in ensured by induction heating. Plastometer contains the sensor of temperature and control of adjusted temperature. The sample is placed in a hermetic glass tube. This enables the sample heating in other atmospheres, besides air, eventually immediate cool down by water. Scanning of twist rate, torque, axial force and temperature is recorded as data file on control computer.

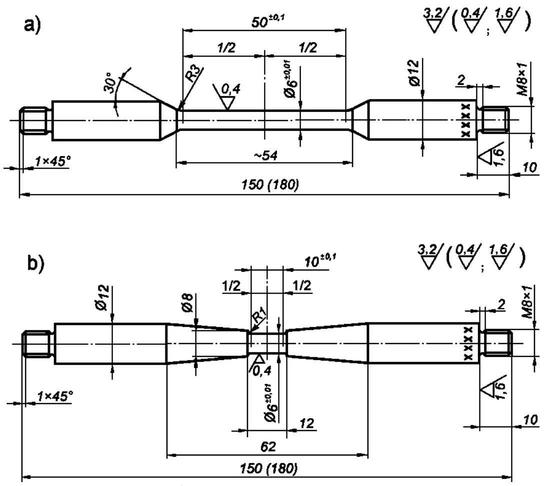

Fig.1 Testing samples for torsion tests a) L=500 mm, b) L=10 mm

## 2. Calculation of deformation

Value of torsion shear strain $\boldsymbol{\gamma}$ is established from the number of twists and used dimensions of a sample

$$\gamma = \frac{2\pi \cdot R}{L} n_s \tag{1}$$

where $\boldsymbol{\gamma}$ is relative torsion shear strain (shear)

**L** – gauge length of sample

**R** – radius of sample, R=D/2

$\mathbf{n_s}$ – number of twists

Torsion shear strain rate $\dot{\gamma}$ determine from the equation

$$\dot{\gamma} = \frac{2\pi \cdot R}{L} \cdot \frac{n}{60} \quad [s^{-1}] \tag{2}$$

where **n** is twist rate in round per minute. Relation between results from torsion test for determined conditions (strain value, strain rate, temperature of deformation) and stress obtained from tensile tests in accordance with theory of intensity stability for tangential stress gives the next equation

$$\sigma_p = \tau\sqrt{3} = \frac{\sqrt{3}}{2\pi \cdot R^3} \cdot 3T_k \tag{3}$$

where $\boldsymbol{\sigma_p}$ is comparable shear stress (basic shear resistance). True deformation $\boldsymbol{\varphi}$ is expressed by relation which results from normal and shear stresses, see the equation (3)

$$\varphi = \frac{\gamma}{\sqrt{3}} \tag{4}$$

Substituting the equation (3) into the equation (4) gives the relation

$$\varphi = \frac{1}{\sqrt{3}} \cdot \frac{2\pi \cdot R \cdot n_s}{L} \tag{5}$$

This relation is used at Department of Process Modeling and Engineering Medicine of the Silesian University of Technology in Katowice [9]. Company MATERIÁLOVÝ A METALURGICKÝ VÝZKUM, Ostrava-Vítkovice uses the following relation to establish logarithmic deformation $\boldsymbol{\varphi}$ for torsion tests [10]

$$\varphi = \frac{2}{\sqrt{3}} \arg\sinh\left(\frac{\pi \cdot \overline{R} \cdot n_s}{L}\right) \tag{6}$$

where $\overline{R}$ stands for equivalent radius determined from true radius **R**

$$\overline{R} = \frac{2}{3} R \tag{7}$$

Computational relation for logarithmic deformation $\boldsymbol{\varphi}$ is

$$\varphi = \frac{2}{\sqrt{3}} \arg\sinh\left(\frac{2\pi \cdot R \cdot n_s}{3L}\right) \tag{8}$$

Institute of Metal Forming TU Bergakademie in Freiberg uses again the equation (6) to analyze logarithmic deformation $\boldsymbol{\varphi}$ for torsion test. The difference is that equivalent radius $\overline{R}$ is determined by the equation (9)

$$\overline{R} = \frac{3}{4} R \tag{9}$$

Final computational relation for logarithmic deformation **φ** is

$$\varphi = \frac{2}{\sqrt{3}} \arg\sinh\left(\frac{3\pi \cdot R \cdot n_s}{4L}\right) \tag{10}$$

They use radius of sample R=3 mm and length of twisted part of sample L=15 mm. Likewise for true rate of deformation $\dot{\varphi}$ is

$$\dot{\varphi} = \frac{\dot{\gamma}}{\sqrt{3}} \quad [s^{-1}] \tag{11}$$

## 3. Comparision of computational relations for torsion deformation

As stated in the previous section, several relations, like the equations (5), (8) and (10), can be used for the calculation of deformation. To compare calculated results of deformation **φ** we need to introduce relative torsion shear strain $\boldsymbol{\gamma_s}$ (shear), which is defined by the equation (1). By introducing the substitution **γ** the equations (5), (8) and (10) can be written as

$$\varphi = \frac{2}{\sqrt{3}} \cdot \frac{\gamma_s}{2} \tag{12}$$

$$\varphi = \frac{2}{\sqrt{3}} \cdot \arg\sinh\left(\frac{1}{3} \cdot \gamma_s\right) \tag{13}$$

$$\varphi = \frac{2}{\sqrt{3}} \cdot \arg\sinh\left(\frac{3}{8} \cdot \gamma_s\right) \tag{14}$$

Institute of Metal Forming TU Bergakademie in Freiberg uses software AUK [11] where torsion deformation **φ** is stated with the equation

$$\varphi = \frac{2}{\sqrt{3}} \cdot \ln\left(\frac{\gamma_s}{2} + \sqrt{\frac{\gamma_s}{4} + 1}\right) \tag{15}$$

Hyperbolic function **argsinh** in the equation (13) can be written through natural logarithm. Then the equation (13) gives the relation

$$\varphi = \frac{2}{\sqrt{3}} \cdot \ln\left(\frac{\gamma_s}{3} + \sqrt{\left(\frac{\gamma_s}{3}\right)^2 + 1}\right) \tag{16}$$

Similarly is realized transformation of the equation (14)

$$\varphi = \frac{2}{\sqrt{3}} \cdot \ln\left(\frac{3}{8} \cdot \gamma_s + \sqrt{\left(\frac{3}{8} \cdot \gamma_s\right)^2 + 1}\right) \tag{17}$$

When comparing the equation (15) with the equations (16) and (17) we can see that they are very similar. By transformation of the equations (13) and (14) into logarithmic shape, it is possible to state that equations (13) to (15) represent logarithmic deformation **φ**. Logarithmic deformation is often known in references as **ε**, or strain rate $\dot{\varepsilon}$. It is necessary to state that equations (13) and (16) are identical, or the equations (15) and (17) are also identical. Comparison of the equations (12) to (16) for calculation of torsion deformation **φ** is in **Fig. 2**. Results of deformation calculated from the equations (13) to (15) are slightly different. Calculation of deformation realized from the equation (12) represents substantially different results from those calculated from logarithmic definition of torsion deformation, see [12] and [13]. That is why experimental laboratories prefer calculation of torsion deformation according to the equations (13) to (15). In order to ensure that measured and calculated values of torsion deformation **φ** are unique, it is necessary to state calculation relation according to which the deformation was calculated to the results of exams. This would enable general verification of measured results.

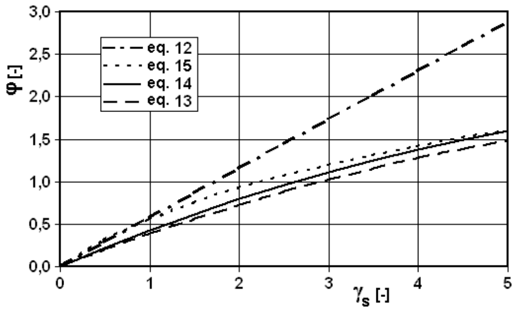


Fig.2 Comparision of computational relations for torsion deformations **φ**

## 4. Experimental tests

Brass Ms70 was used for experiments (chemical composition of brass Ms70 see in **Table 1**. From the chemical composition, it can be stated that we deal with fine brass determined for cartridge manufacture and process of deep drawing. Experimental material was composed of Ms70 brass bars with **a** diameter of 10 mm which were provided by a manufacturer from usual production. Final cold forming by pulling was realized from full annealing state on combined pulling machine to straight shape with final diameter 10 mm and relative deformation **ε** =11,0 %. Samples (bars) – short bars D x L =6 x 10 mm as well as long bars D x L = 6 x 50 mm – which are showed in **Fig. 1**. were manufactured. It was necessary to verify the ability of laboratory to perform hot torsion tests for brass Ms70 on these bars since this material was not examined in the laboratory before. The main problem consisted in sensor of temperature as the working range was for higher forming temperatures (orientation on usual and high alloyed steels), while brass has significantly lower formability temperatures. The temperature of T=850 °C was suggested for the first forming and tests. Since there was no previous experience with torsion test of brass Ms70, planned twist rate expressed by speed of torsion **n** for short samples according to **Table 2** was suggested. Where the meaning of particular columns is the following:

**n** – planned speed of torsion [rpm]
$\mathbf{t_{sum}}$ – total actual time of torsion test [s]
$\mathbf{T_{k\,max}}$ – highest torque during torsion test [Nm]

| | |
|---|---|
| $\mathbf{F_{tens\ max}}$ | – highest tension force during torsion test [N] |
| $\mathbf{F_{pres\ max}}$ | – highest pressure force during torsion test [N] |
| $\mathbf{T_{act}}$ | – average temperature during torsion test [°C] |
| $\mathbf{n_{rupt}}$ | – number of revolutions till rupture (fracture) [round] |
| $\mathbf{n_{act}}$ | – average true speed of torsion [rpm] |
| $\boldsymbol{\gamma}$ | – relative torsion shear strain [–] |
| $\dot{\boldsymbol{\gamma}}$ | – torsion shear strain rate [$s^{-1}$] |

Table 1 Chemical composition of brass Ms70 for torsion tests [weight %]

| Element | **Cu** | **Pb** | **Sn** | **Fe** | **Ni** | **Mn** | **Al** | **Si** |
|---|---|---|---|---|---|---|---|---|
| Contents | 70,39 | 0,0004 | 0,0042 | 0,0232 | 0,0022 | 0,0003 | 0,0012 | 0,0002 |
| Element | **As** | **Sb** | **Bi** | **Cr** | **Cd** | **Ag** | **P** | **Zn** |
| Contents | 0,0001 | 0,0031 | 0,0001 | 0,0001 | 0,0001 | 0,0001 | 0,0002 | rest |

Table 2 Torsion test of brass Ms70 on samples $\phi$6 x 10 mm and temperature T=850 °C

| n [rpm] | $t_{sum}$ [s] | $T_{k\ max}$ [Nm] | $F_{tens\ max}$ [N] | $F_{pres\ max}$ [N] | $T_{act}$ [°C] | $n_{rupt}$ [round] | $n_{act}$ [rpm] | $\gamma$ [–] | $\dot{\gamma}$ [$s^{-1}$] |
|---|---|---|---|---|---|---|---|---|---|
| 12 | 306,40 | 1,02 | 104,83 | -27,56 | 841 | 56,95 | 11,15 | 107,35 | 0,35 |
| 80 | 38,16 | 1,55 | 234,08 | -42,33 | 853 | 53,87 | 84,70 | 101,54 | 2,66 |
| 160 | 15,01 | 1,52 | 249,92 | -31,93 | 851 | 41,72 | 166,76 | 78,64 | 5,24 |
| 800 | 2,76 | 2,12 | 396,20 | -58,11 | 868 | 37,98 | 825,62 | 71,59 | 25,94 |

Table 3 Torsion test of brass Ms70 on samples $\phi$6 x 50 mm and temperature T=850 °C

| n [rpm] | $t_{sum}$ [s] | $T_{k\ max}$ [Nm] | $F_{tens\ max}$ [N] | $F_{pres\ max}$ [N] | $T_{act}$ [°C] | $n_{rupt}$ [round] | $n_{act}$ [rpm] | $\gamma$ [–] | $\dot{\gamma}$ [$s^{-1}$] |
|---|---|---|---|---|---|---|---|---|---|
| 16 | 189,5 | 0,64 | 106,58 | -68,54 | 844 | 48,78 | 15,45 | 18,39 | 0,10 |
| 40 | 97,0 | 0,91 | 103,35 | -107,01 | 842 | 67,36 | 41,66 | 25,39 | 0,26 |
| 80 | 83,0 | 1,09 | 161,34 | -27,09 | 845 | 117,01 | 84,58 | 44,11 | 0,53 |
| 160 | 30,5 | 1,28 | 182,09 | -27,52 | 852 | 84,57 | 166,36 | 31,88 | 1,05 |

Similar tests were realized for long samples D x L = 6 x 50 mm. Speeds of torsion were used according to **Table 3** where measured and calculated values are listed. Protocol with time behavior of measured values is made for each torsion test. The protocol is later complemented with behavior of measured values in dependence on the number of twists.

Example from experiment for sample with dimensions D x L = 6 x 10 mm, temperature T=850 °C and speed of torsion n=160 rpm, can be seen on the following **Fig. 3, 4, 5 and 6**. Time behavior of sample heating is on **Fig. 3**. Dependence of torque on the number of twists is on **Fig. 4**. We can see stress peak on the curve, behind which there is dynamic recrystallization, despite the fact that torsion deformation continues. The course of normal force in dependence on the number of twists is stated on **Fig. 5**. The picture shows that pressure force emerges at first and is later changed to axial tension force. Temperature behavior during deformation is stated on **Fig. 6**. In [14] empirical calculation of strain rate which is no longer used in laboratories is stated. Used material for torsion tests was in deformed state. Investigation of influence of full annealing state and deformed state of brass Ms70 on results of torsion tests was not realized. Results of papers [15] and [16] performed on aluminum alloy suggest that some differences can be expected for brass to. Analysis of achieved speeds of strain rate during extrusion pressing was followed by the decision that further torsion tests will be performed only on short samples D x L = 6 x 10 mm. Long samples D x L = 6 x 50 mm have too small range of strain rates for the needs of simulation of extrusion pressing conditions for brass Ms70. Short samples are suitable for higher strain rates; long samples for the lower strain rates. Time behavior record of start phase to reach required higher revolutions of required higher speed of torsion (for example 800 rpm) showed that during starting-up phase of torsion, inertial masses of plastometer are significantly manifested. Thus, it was recommended to use twist rate maximally to 400 rpm. On the basis of experience, plan of torsion tests which in the full range covers working range of temperatures and strain rates during extrusion pressing of brass Ms70 was elaborated.

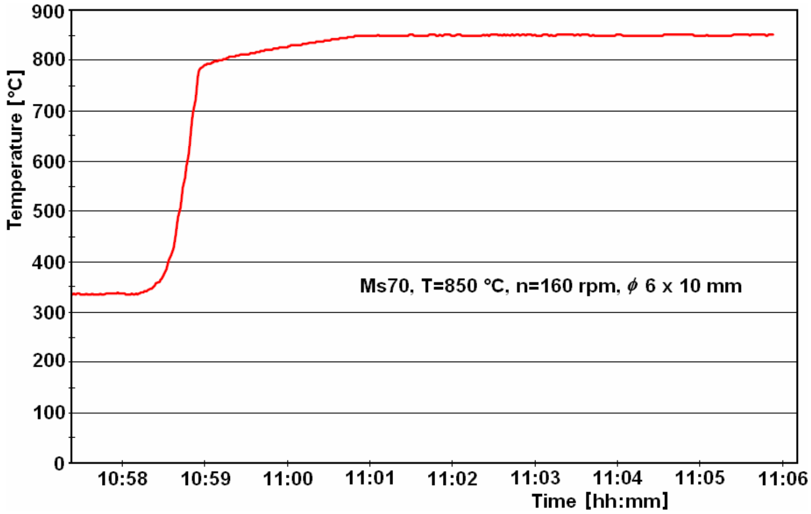

Fig.3 Time behavior of sample heating

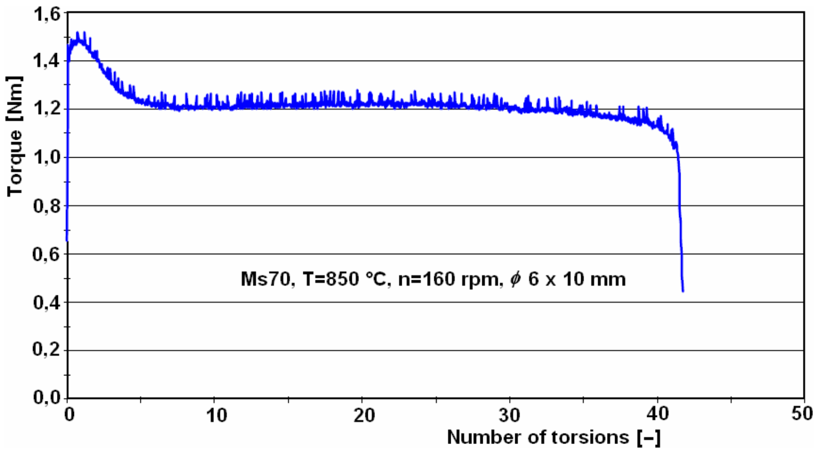

Fig.4 Torque behavior on number of torsions

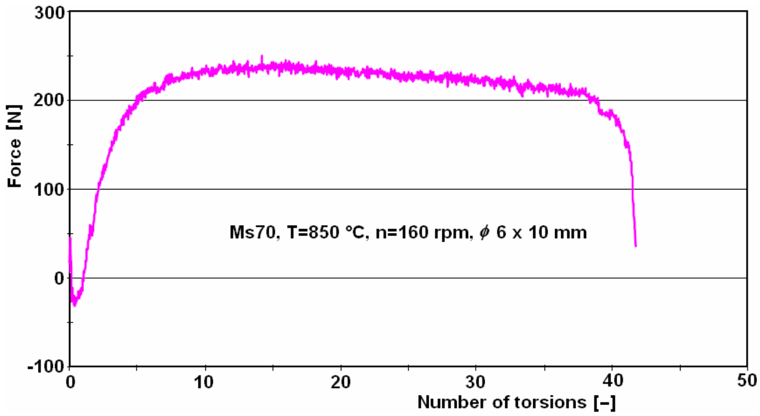

Fig.5 Tension force behavior on number of torsions

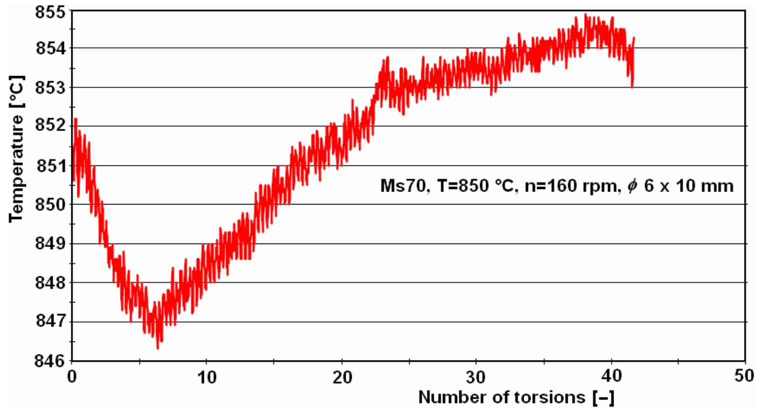

Fig.6 Temperature behavior on number of torsions during deformation

## Conclusion

The submitted study represents the introduction into plastometric examinations of heavy nonferrous metals, namely brass Ms70. Relations to determine deformation during torsion test were analyzed. From the analysis it results that particular laboratories do not calculate torsion deformation from unique computational relations but they correct computational relations in accordance with their experience. It was stated on the basis of achieved experience that further torsion tests for simulation of extrusion pressing of brass Ms70 will continue on short samples.

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