# QUANTITATIVE PARAMETERS OF DEFORMATION OF COLD ROLLED METAL MATERIALS

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# KVATITATÍVNE PARAMETRE DEFORMÁCIE KOVOVÝCH MATERIÁLOV ZA STUDENA

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**Abstrakt**

V práci sú analyzované kvantitatívne parametre deformácie rôznych kovových materiálov. Deformácia bola uskutočnená valcovaním za studena na laboratórnej DUO stolici. Vzorky z nízkouhlíkovej ocele, hliníka, olova a medi s rôznymi východiskovými rozmermi boli deformované. Redukcia hrúbky vzoriek sa menila od 15% do 90%, s krokom 15%.

Základné kvantitatívne ukazovatele deformácie, ako je predĺženie, rozšírenie a redukcia hrúbky sa vypočítali a získané hodnoty ukazovateľov deformácie sa analyzovali. Analyzovaný bol vplyv stupňa deformácie, geometrických parametrov vzoriek a typu materiálu na kvantitatívne parametre deformácie. Ukázalo sa, že stupeň deformácie a typ materiálu majú najväčší vplyv na kvantitatívne parametre deformácie.

Stupeň deformácie má najväčší vplyv na parametre predĺženia – na 282%, menší vplyv na parametre redukcie hrúbky – na 75,1% a najmenší vplyv na parametre rozšírenia – na 7,6%.

Hodnoty parametrov deformácie sú rozličné pre rozličné kovové materiály. Hliník má najvyššiu hodnotu predĺženia a meď najnižšiu. Pre ukazovateľ rozšírenia je to opačné. Typ materiálu ovplyvňuje hlavne parametre rozšírenia. V závislosti od kovového materiálu sa hodnoty ukazovateľov rozšírenia líšia o 195%.

Geometrické parametre vzoriek majú najväčší vplyv na parametre deformácie. So vzrastom východiskovej hrúbky a šírky vzoriek, hodnoty všetkých ukazovateľov deformácie sa zvyšujú.

**Abstract**

In this paper, quantitative parameters of deformation of different metal materials have been analysed. The deformation was made by cold rolling on the laboratory two-high rolling stand. The samples of low-carbon steel, aluminium, lead and copper, with different initial dimensions, were deformed. Reduction of the samples thiskness has been varied drom 15% to 90%, by step of 15%.

Basic quantitative indicators of deformation, sucha s elongation, spreading and thickness reduction, have been calculated and the obtained values of indicators of deformation have been analysed. The influence of degree of deformation, geometrical parameters of samples and type of materials on the quantitative parameters of deformation has been analysed. It was shown taht the degree of deformation and type of material have the greatest influence on the quantitative parameters of deformation.

The degree of deformation has the gretest influence on the parameters of the elongation – to 282%, less influence on the parameters of the thickness reduction – to 75,1% and the least influence of the parameters of the spreading – to 7,6%.

The values of the deformation parameters are different for different metal´s material. Aluminium has the highest values of elongation and copper – the lowest. For the indicators of spreading is opposite. Type of material especially influence on the spreading parameters. In dependence of the metal´s material, the values of the indicators of spreading differ to 195%.

The geometrical parameters of the samples have the greatest influence on the defromation parameters. With the increase of the initial thickness and width of the samples, the values of all deformation indicators are increasing.

**Keywords**: quantitative parameters of deformation, thickness reduction elongation, spreading, cold rolling, metal’s materials

## 1. Introduction

Deformation by the cold rolling gives demanded and previous defined metal's thickness [1]. In the same time, rolled material is spreading and its mechanical and technological properties are changing [2, 3]. Quantitative indicators of deformation define the change of the geometry of the deformed materials. Quantitative indicators of deformation depend on the conditions of deformation and type of material [3-5]. In this work an influence of some of them - degree of reduction, geometry and type of material, on quantitative parameters of deformation was analysed.

## 2. Experimental

Experimental procedure consists of cold deformation of total 16 samples of aluminium, lead, copper and low-carbon steel. Chemical composition of the samples is given in Table 1.

Table 1 Chemical composition of the samples

| Sample | Chemical composition [%] |
|---|---|
| Aluminium | Al - 99.8; Si - 0.15; Cu - 0.02; Ti - 0.03 |
| Lead | Pb - 99.99 |
| Cooper | Cu - 99.75 |
| Steel | Fe - 98.78; C - 0.08; Si - 0.21; Mn - 0.49; P - 0.005; S - 0.007; Al - 0.03; Cu - 0.30; Ni - 0.098 |

Initial dimensions of the samples from different materials were equal - the thickness and the length were 50 mm and the width was 80 mm. Thickness, width and length of the samples from steel and lead are varied from 3 mm to 6.4 mm, from 36.7 mm to 42.5 mm and from 80 to 364 mm, respectively.

The samples were deformed by cold rolling on laboratory two-high rolling stand with plain roll. The diameter of working rolls is 125 mm, and its working length is 200 mm. The distance between the rolls is regulated with precision of $10^{-2}$ mm. The rolling speed was 0.163 m/s. The major part of the samples was deformed with reduction degree from 15% to 75%, by step of 15% and the minor part of the samples of steel and lead was deformed to 90%.

## 3. Quantitative indicators of deformation

The change of geometrical parameters of the samples (thickness, length and width) was measured after every rolling pass. The quantitative indicators of deformation were calculated by the well-known equations as follow [3, 6]:

- absolute parameters of deformation (elongation, $\Delta L$, spreading, $\Delta B$, thickness reduction, $\Delta H$), as absolute difference of the geometrical parameters before and after deformation,
- coefficients of deformation (elongation coefficient, $\lambda$, spreading coefficient, $\beta$, coefficient of thickness reduction, $\eta$), as the ratio of the geometrical parameters before and after the deformation;
- relative parameters of deformation (relative deformation of thickness, $\varepsilon_H$, relative deformation of width, $\varepsilon_B$, relative deformation of length, $\varepsilon_L$) in every rolling pass, as difference of the geometrical parameters of the samples, expressed in percent;
- total relative parameters of deformation after the last rolling pass ($\varepsilon_{H\Sigma}$, $\varepsilon_{B\Sigma}$, $\varepsilon_{L\Sigma}$) and total spreading ($\Delta B_\Sigma$), as difference the of geometrical parameters of the sample before and after the deformation, expressed in percent;
- length and surface of the area of deformation ($L_d$, $F$),

The obtained values of the quantitative indicators of deformation were analysed. Then, theirs minimal and maximal values were considered. The influence of the deformation degree, the geometry of the samples and the type of the material on the quantitative parameters of deformation was also considered.

### *3.1 Quantitative indicators of elongation*

The length of the samples was measured after every rolling pass. Using the suitable mathematical expressions, next quantitative indicators were calculated: elongation, $\Delta L$, elongation coefficient $\lambda$, relative deformation of length in every rolling pass, $\varepsilon_L$, and total relative indicators of deformation of length, $\varepsilon_{L\Sigma}$. Minimum and maximum values of coefficients $\lambda$ and $\varepsilon_L$, as well as the values of $\varepsilon_{L\Sigma}$, are given in the Table 2.

Table 2 Quantitative parameters of elongation of the samples

| Samples | $\lambda$ | | $\varepsilon_L$ [%] | | $\varepsilon_{L\Sigma}$[%] |
|---|---|---|---|---|---|
| | min | max | min | max | |
| Aluminium | 1.177 | 1.597 | 17.71 | 59.75 | 281.93 |
| Lead | 1.155 | 1.554 | 15.51 | 55.41 | 280.13 |
| Cooper | 1.166 | 1.561 | 16.63 | 56.12 | 271.73 |
| Steel | 1.194 | 1.581 | 19.44 | 58.14 | 280.19 |

Comparison of the obtained quantitative parameters of elongation indicates on theirs mutual differences. The values of the coefficient $\lambda$ are mutual differ of about 38% and the values of the coefficient $\varepsilon_L$ - 285%. Previously defined values of the coefficient of total elongation, $\varepsilon_{L\Sigma}$, have minimal difference - 3.8%. In Table 2 are also given the values of the coefficient of total elongation after 75% of the thickness reduction. The values of this indicator are much greater than ones after 15% of thickness reduction. Fig. 1 shows the coefficient $\varepsilon_L$ in dependence on the thickness reduction for different metal materials.

In dependence of the reduction, the values of relative elongation for aluminium and copper are different. On the whole, the values of the coefficient of elongation for aluminium are the highest and for copper are the smallest. Their mutual difference is the smallest in the beginning of the deformation and the biggest in the interval from 45 and 60% of the deformation and it amounts 16.7%. In the end of the deformation, after 75% of thickness reduction, their difference is 7.8%.

The degree of reduction is of essential influence to the elongation. In the analysed interval of 75% of thickness reduction, the value of relative elongation of the aluminium, $\varepsilon_L$, is growing up for 375%.

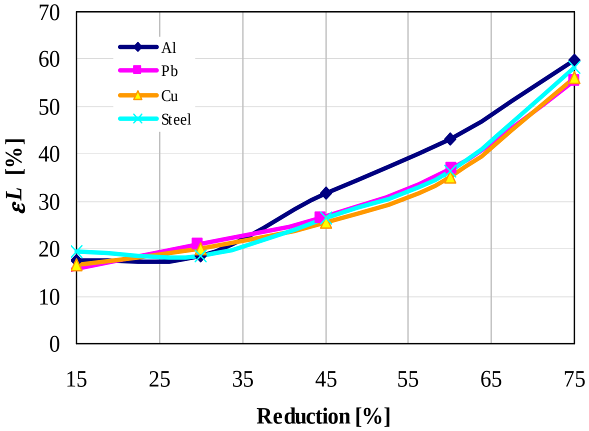


Fig.1 Coefficient of elongation, $\varepsilon_L$, in dependence of the thickness reduction

The influence of the geometrical parameters of the samples on the parameters of deformation, above all, the influence of the initial thickness of the samples, was analysed on the samples of lead and low-carbon steel. The analyses have shown that the thickness of the samples influences on the elongation parameters. With the growing up of the initial thickness of the samples, all parameters of the elongation are growing up to about 2.5%. Maximum difference of 16.4% is noticed in the values of total relative elongation after reduction of 75% for steel samples with thickness of 3 mm and 6.4 mm.

### *3.2 Quantitative indicators of thickness reduction*

The quantitative indicators of the thickness reduction were estimated with measuring of the samples thickness after each rolling pass and then with calculations using the corresponded mathematical expressions. In this way it was estimated the absolute thickness reduction, $\Delta H$, the coefficient of thickness reduction, $\eta$, the relative thickness reduction after each rolling pass, $\varepsilon_H$, and the total relative thickness reduction, $\varepsilon_{H\Sigma}$. Minimum and maximum values of the coefficients $\eta$ and $\varepsilon_H$, as well as the values of $\varepsilon_{H\Sigma}$, are given in Table 3.

Table 3 Quantitative parameters of thickness reduction of the samples

| Samples | $\eta$ | | $\varepsilon_H$ [%] | | $\varepsilon_{H\Sigma}$[%] |
|---|---|---|---|---|---|
| | min | max | min | max | |
| Aluminium | 0.641 | 0.847 | 15.31 | 35.90 | 74.49 |
| Lead | 0.628 | 0.861 | 13.89 | 37.21 | 75.00 |
| Cooper | 0.625 | 0.850 | 15.00 | 37.50 | 75.05 |
| Steel | 0.594 | 0.852 | 15.69 | 38.05 | 75.10 |

The values of the coefficient $\eta$ mutually differ for 45% and $\varepsilon_H$ - 174%. The values of total relative thickness reduction, $\varepsilon_{H\Sigma}$, have the smallest mutual difference - 0.82%.

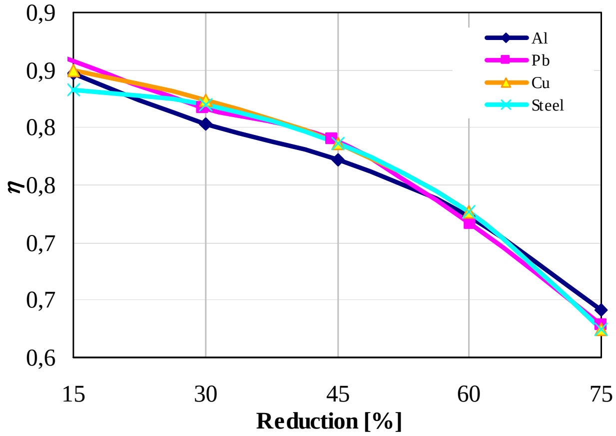


Fig.2 Dependence of the coefficient of thickness reduction, $\eta$, on the thickness reduction for different metal's materiále

The indicators of thickness reduction have approximate values in the whole interval of reduction. The maximum value of the coefficient $\eta$ after reduction of 15% is noticed for lead, and minimum value is noticed for aluminium. The coefficient $\varepsilon_H$ has maximum value for steel and minimum value for aluminium for the most part of interval of the reduction, with mutual difference of 5.9%. This is shown in Fig. 2, where is presented the dependence of the coefficient of thickness reduction on the degree of reduction for different metal's material. After reduction of 30%, the values of the coefficient differ only 2.6% for different materials and after reduction of 45%, their difference is even smaller.

With the increase of the thickness reduction to 75%, the values of the coefficients of thickness reduction are reducing for 45%.

Thickness decreasing of the samples influences on the decreasing of the values of coefficients of thickness reduction. The comparison of the values of this parameter after 75% of reduction shows variation of 5.5%.

### *3.3 Quantitative indicators of spreading*

Some quantitative indicators of spreading were calculated after 80% of reduction: spreading, $\Delta B$, coefficient of spreading, $\beta$, relative spreading after each rolling pass, $\varepsilon_B$, and total relative deformation of the width, $\varepsilon_{B\Sigma}$. The spreading, $\Delta B$, was estimated using the expression of Smirnov [3]:

$$\Delta B = \Delta H\left(1+\frac{\Delta H}{H_0}\right)\left(\sqrt{2}\,\frac{\mu L_d}{H_0}-\frac{1}{2}\frac{\Delta H}{H_0}\right), \tag{1}$$

where is $H_0$ - thickness of the sample before the deformation, $H_1$ - thickness of the sample after the deformation, $\Delta H$- difference of the thickness of the samples ($\Delta H = H_0 - H_1$), $L_d$ - length of the deformation area, $\mu$ - coefficient of the friction.

Minimal and maximal values of the coefficients $\beta$ and $\varepsilon_B$, as well as the values of the total relative deformation of the width, $\varepsilon_{B\Sigma}$, are presented in the Table 4.

Table 4 Quantitative parameters of the spreading of the samples

| Material | $\beta$ | | $\varepsilon_B$ [%] | | $\varepsilon_{B\Sigma}$ [%] | $\Delta B_{max}$ [mm] |
|---|---|---|---|---|---|---|
| | min | max | min | max | | |
| Al | 1.0031 | 1.0084 | 0.31 | 0.84 | 2.64 | 1.57 |
| Pb | 1.0053 | 1.0171 | 0.53 | 1.71 | 5.23 | 2.42 |
| Cu | 1.0087 | 1.0248 | 0.87 | 2.48 | 7.60 | 3.80 |
| Steel | 1.0043 | 1.0171 | 0.59 | 1.71 | 5.71 | 1.78 |

In the relation to the elongation and the thickness reduction, the spreading is the smallest expressed appearance in the cold deformation of the metal's material. While the total elongation reaches up to about 282%, during 75% of thickness reduction, the maximal value of total spreading is only 7.6%. But, the differences appearing between the calculated values of the spreading indicators are high - 700% at the parameter $\varepsilon_B$, i.e., 550% at $\varepsilon_B$.

The highest values of spreading appear in the copper sample and the lowest in the aluminium sample (Table 4). Their mutual difference is 195% (for the parameter $\varepsilon_B$), or 188% and 142% (for the parameters $\varepsilon_{B\Sigma}$ and $\Delta B_{max}$). In Fig. 3 is presented the dependence of total spreading, $\Delta B$, from the degree of reduction for samples of different metal's materials. As Fig. 3 clearly shows, with the increase of the degree of reduction, the value of the total spread is rising. The values of the indicators of spreading of the copper sample in the interval from 15 to 75% are reaching up to 763% (for parameter $\Delta B$) and to 782% (for $\varepsilon_{B\Sigma}$).

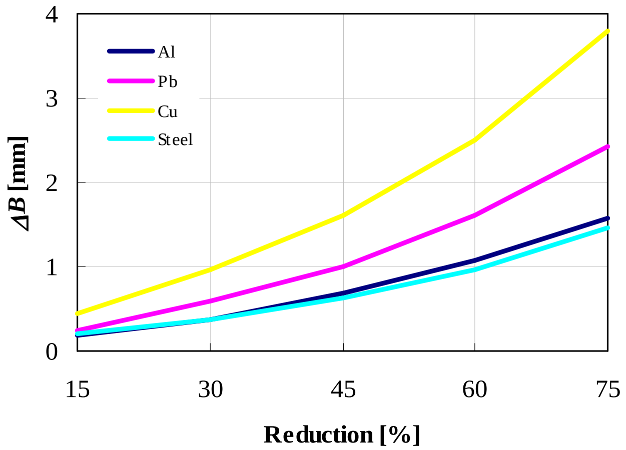


Fig.3 Dependence of the total spreading, $\Delta B$, on the thickness reduction

The thickness of the samples also influences on the spreading. The analysis shows that the spreading is more appearing at the thicker samples. The difference between the spreading of the sample with 3 mm and 6.4 mm is 48%.

## 4. Influence of the degree of reduction, material and geometry of the samples on the quantitative indicators of deformation

Generally speaking, the quantitative indicators of deformation during the cold rolling of different materials have different values. Maximal differences are appearing for relative parameters of deformation ($\varepsilon_L$, $\varepsilon_H$, $\varepsilon_B$) and they vary from 174 to 700%. Also, great difference is appearing for the values of the coefficient of spreading - 188%. Minimal difference of 2.2% is estimated for the previously given total reduction of 75%. These differences are results of different degrees of reduction, different materials and different initial geometrical parameters of the samples.

### *4.1 Influence of the degree of reduction on the quantitative indicators of deformation*

The degree of reduction influences mostly on the quantitative indicators of deformation. In most cases, the degree of the reduction varies from 15% to 75% and in exceptional cases up to 90%. After reduction of 75%, the value of the elongation of the steel sample is increasing for 233% and after 80% - for 409%. After 90% of the reduction, the sample has 4 times smaller thickness, almost 7 times greater length and greater width for 4.76%.

### *4.2 Influence of the material on the quantitative indicators of deformation*

The influence of the type of the material on the quantitative indicators of deformation was researched in the processes of cold rolling of the samples of low-carbon steel, aluminium, lead and copper.

The analysis of the obtained values of the elongation indicators points out their dependence of the deformed material. In relation to the analysed materials, aluminium has the highest and copper has the lowest values of the elongation, as presented in the Fig. 1. In dependence of the degree of deformation, the difference of the values of coefficient of elongation reaches to 16.7% (Table 2).

The values of the indicators of thickness reduction are also different for different materials. They are the highest values for lead ($\eta$) and steel ($\varepsilon_H$), and the lowest values for aluminium ($\eta$, $\varepsilon_H$). In dependence of the material, the values of thickness reduction have maximal difference of 5.9%.

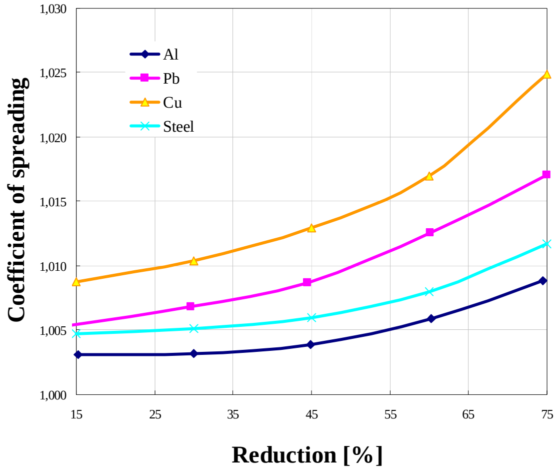


Fig.4 Coefficient of spreading during the deformation for different metal's materials

In relation to the indicators of elongation and thickness reduction, material has the greatest influence on the indicators of spreading ($\varepsilon_B$, $\varepsilon_{B\Sigma}$, $\Delta B_{max}$). The values of the indicators of spreading are the highest for copper and the lowest for aluminium, with mutual differences from 142 to 195% (Table 4, Fig. 3.). In Fig. 4 are presented the changes of the coefficient of spreading for samples of different metal's materials in reduction interval of 75%.

### *4.3 Influence of the geometrical parameters of the sample on the quantitative indicators of deformation*

In the process of cold rolling, some of the samples have different initial geometrical parameters. The analysis of the obtained values has shown that the initial thickness of the samples influence on the quantitative indicators of deformation.

With the increase of the initial thickness of the samples, the values of all deformation indicators are increasing.

The values of elongation indicators of the steel samples with thickness from 3 to 6.4 mm have mutual difference of average 2.5%. The maximal difference of 16.4% is appearing between the values of total relative elongation of the steel samples with thickness of 3 and 6.4 mm after the reduction of 75%. Fig. 5 shows elongation of the steel samples with different initial thickness in the process of deformation.

The initial thickness also influences on the spreading. The spreading is greater for thicker samples. In Fig. 6 is shown the change of the width of the steel samples with the different initial thickness. Total spreading for the sample with thickness of 3 mm is 1.1%, and for the sample with thickness of 6.4 mm - 9%. Thus, for the change from 3 to 6.4 mm, which is equal to 113%, the spreading is increased 8 times.

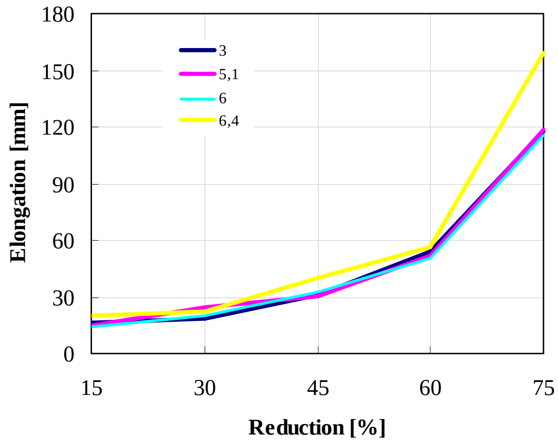


Fig.5 Influence of the initial thickness of the samples on the elongation

The initial width also influences on the indicators of deformation. With the increase of the initial width for 5.8 mm (from 36.7 to 42.5 mm), after reduction of 75% the values of relative elongation are greater for 13.8%, the values of relative spreading for 14% (Fig. 7).

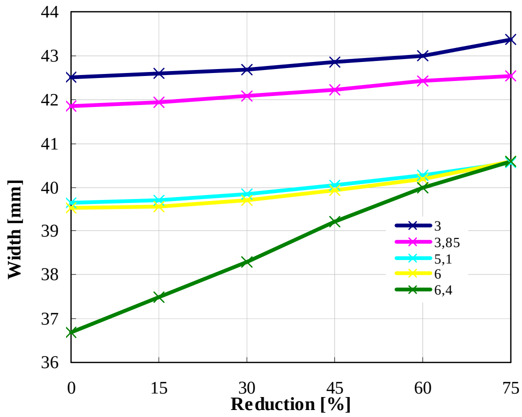


Fig.6 Influence of the initial thickness on the samples on the spreading

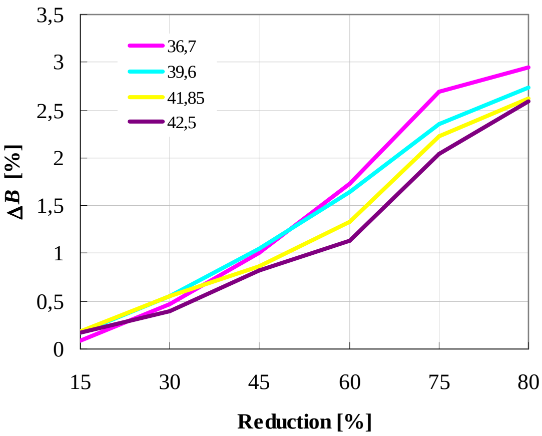


Fig.7 Influence of the initial width of the samples on the relative spreading

## Conclusions

The basic quantitative indicators of deformation in the process of cold rolling of different metal's material were estimated. After reduction of 75%, the highest values have coefficients of total elongation and coefficient of thickness reduction, and the lowest value has coefficient of spreading - 285%, 174% and 7.6%, respectively.

The values of the quantitative indicators of deformation have great mutual differences. The greatest differences are appearing for the relative indicators of deformation ($\varepsilon_L$, $\varepsilon_H$, $\varepsilon_B$) - between 170 and 700%, as well as for the coefficient of total spreading - 188%. These differences are results of different degree of reduction, material and geometry of the samples.

The greatest influence on the quantitative indicators of deformation has the degree of reduction, then the type of material and the geometry of the samples.

The degree of reduction mostly influences on the parameters of spreading and elongation. After reduction of 75%, the values of the indicators of spreading are higher for 782%

($\varepsilon_{B\Sigma}$) and to 763% ($\Delta B$). The values of the total relative elongation increased up to 409% after reduction of 80% and to 680% after reduction of 90%.

Type of metal's material also influence on the indicators of deformation. Aluminium has the highest values of elongation and copper - the lowest. For the indicators of spreading is opposite: the highest value has copper and the lowest aluminium. The type of material influences mostly on the spreading of the samples. In dependence of the material, the values of the indicators of spreading are different even for 195%.

The geometrical parameters of the samples most influence on the spreading. With the increase of the thickness of the sample for 113%, their spreading is increased 8 times and the elongation for 16.4%.

With the increase of the sample width for 16%, the values of the indicators of the elongation and spreading are increasing for approximately of 14%.

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