EFFECT OF THE MINIATURIZATION IN THE FORMING PROCESS

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Abstract. *The miniaturization trend is increasing the demand for studies of manufacture processes from microcomponents. This work intends to study the differences of the effect of the metal forming for macro and microcomponents, simulating and comparing with experimental procedures. A bibliographical revision is proceeded initially from the carried through studies already made in this area. Through a simulational software, the finite elements method (FEM) for the study of the influences in question will be used.*
Keywords: *scale effect, forming process, simulation, manufacture.*

1. Introduction

The last decade presented a great increase in the research and application of microcomponents. The consequence of this development can be seen in popular products as cameras inlaid in handy phones and in high precision ink jet printer devices and also in other branches as medicine and the automobile. However, the trend of the miniaturization generated a certain discomfort for the industry, because this type of component needs differentiated treatment, not counting on the aid of the theory already known for macro components. For this reason, the manufacture process of microcomponents is based on empirical and individual results of manufacture, being one of the challenges of the new generation to study the scale effect in order to create new techniques of viable production and with low level of waste. In figure 1 we can see examples of microcomponents.

Figure 1: Examples of microcomponents.

As an alternative, it is used the forming process, that normally provides viable processes of production, besides presenting many advantages as the economy of material, the control of mechanical properties, high productivity and low ambient impact [1, 3, 4]. The process of numerical simulation through finite elements is becoming an important instrument for the understanding of the effect of miniaturization [2], so that the results from the simulations, when well treated, are very close to the results obtained from experimental procedures.

2. Applications and limits

The trend of the miniaturization is stronger in the electronics industry, where every day a new function is adapted to reduce the size of equipments. Technologies that were until some time impracticable became possible with the reduction of the scale of the components [8]. One of the major problems still faced in the miniaturization process is that the technology known and established for macrocomponents cannot be proportionally spaced out and be applied for microparts. Figure 2 evidences the main problems to be treated when working with microparts. Beyond all influence of the microstructure of the material, the type of application of the part can define the process of manufacture and the correct tool to be used. Alternative methods of manufacture need to be developed to supply the demand of the process [9]. The study of the microforming involves different areas as material properties, processes, tools and machines.

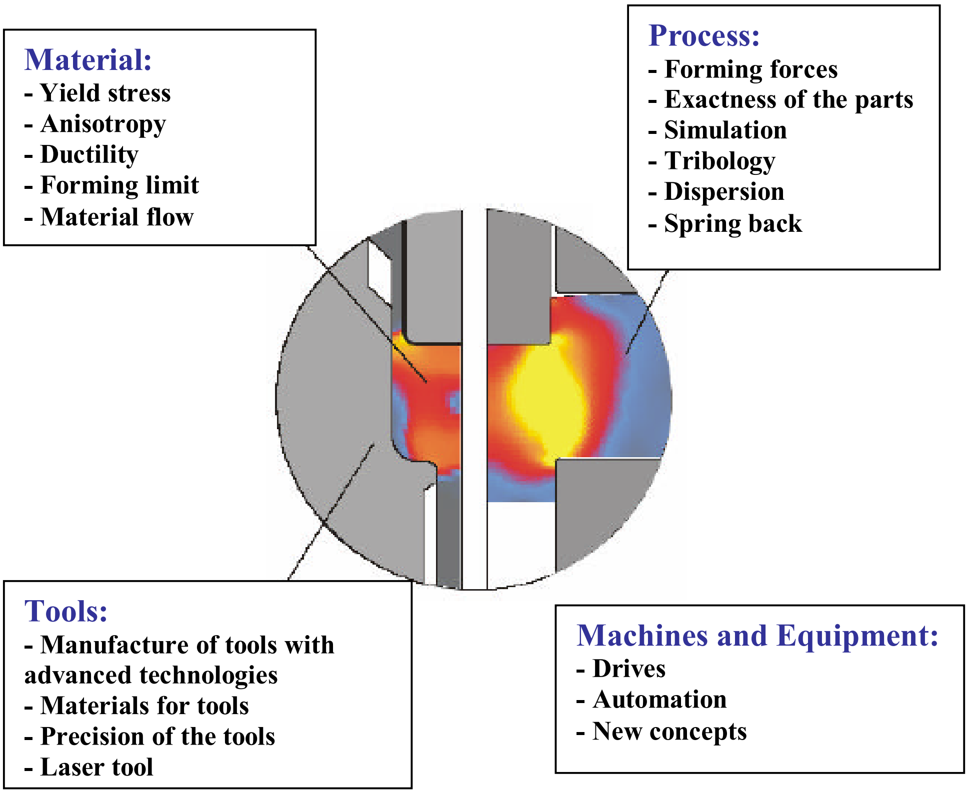

Figure 2: Problems of the micro world forming (Geiger et. Al.) [8]

3. Effect of the miniaturization

3.1. Material Behavior

The scale effect is a phenomenon that describes the difference of behavior of a material in a forming process, whose scale was reduced. The effect of miniaturization in the yield stress is related with the increase of the amount of superficial grains when it has reduction in the dimensions of the body while the grain size continues the same [4, 10]. In figure 3 it is shown the difference between a monocrystalline material and a polycrystalline one. During the forming process the external grains move with smaller forces when compared with the grains that are internal to the volume. In consequence, the yield stress must decrease with the reduction of the dimension of the manufactured parts [10]. Due to the fact that the free surfaces don't present a well definite and comparable border to the element of superficial grain, the movement of the discordances in surface grains is not as restricted as for the internal grains. The yield stress of the internal grains is similar to a common crystalline aggregate [6]. Also for the temperature field, the miniaturization of the dimensions causes changes in the boundary conditions during the forming process [3]. Finally it is possible to reduce the element until it has only one grain in the interior of its volume [4, 5]. The internal grains suffer a resistance to the different plastic deformation from the grains of the edge of the volume, therefore the analysis of the border effect is especially important for microforming.

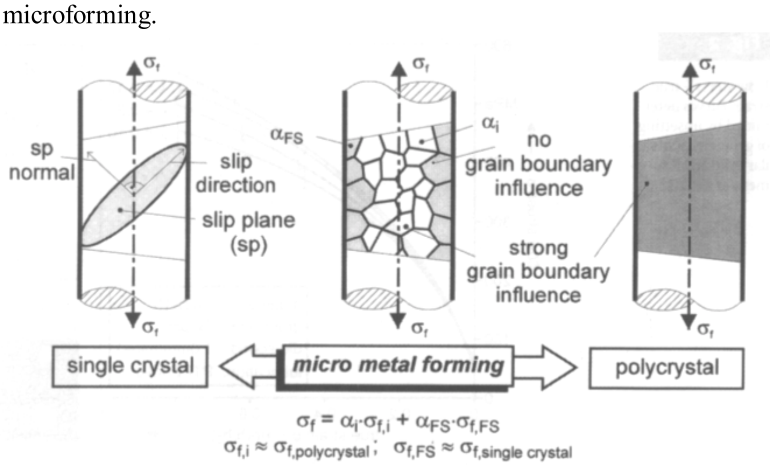

Figure 3: Beddings of the plasticity in metals mono and I polished crystalline. (Messner 1998) [10]

3.2.Visioplasticity

Visioplasticity and optical measurement of force are applied to evaluate material characteristics in order to produce models in FEM and to study the behavior of the deformation in homogeneous and non-homogeneous materials. The orientation of the grains that cause different resistance against the deformation has effect in the force distribution when it exist only few grains in the deformed area. For polycrystalline materials, the force is homogeneous. In the case of few grains in the deformed area, only the grains with favorable orientation are deformed. Figure 4 shows the influence of the granulation and the state of the material (hard state and annealing). When the material is annealing, its grains increases and present a coarse distribution, however when the material is in hard state, its lines are more homogeneous.

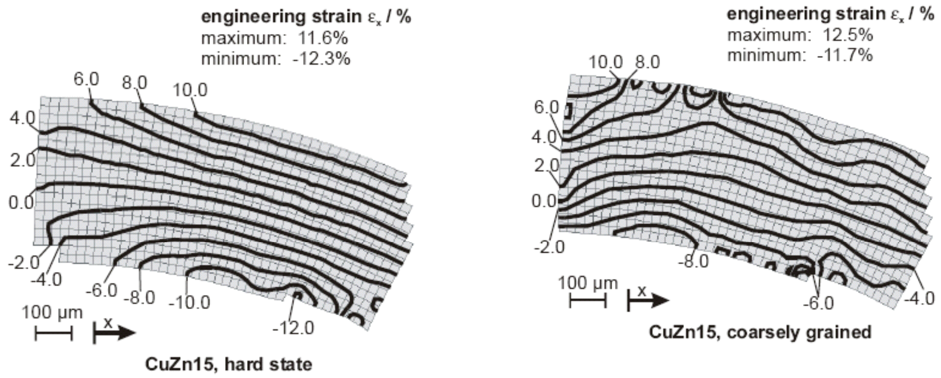

Figure 4: Influence of the granulation (a) more uniform distribution hard state material. (b) Non homogeneous distribution of the deformations for coarse granulation material [5].

4. Miniaturization, micro structural heterogeneities and scale effect

Many local events that influence the dynamic microstructure occur during the deformation (figure 5), resulting in the heterogeneities of the deformation. This behavior is important for the study of the scale effect during the miniaturization of the processes of manufacture in the microforming, because the heterogeneities contribute for the inability of the forecast of the behavior of the strain hardening and the changes of orientation during the deformation. In a monocrystal deformation, part of the grain suffers rotation in a direction and another part in the opposing direction, generating, in the interface of these rotations the "transistion bands". [7]

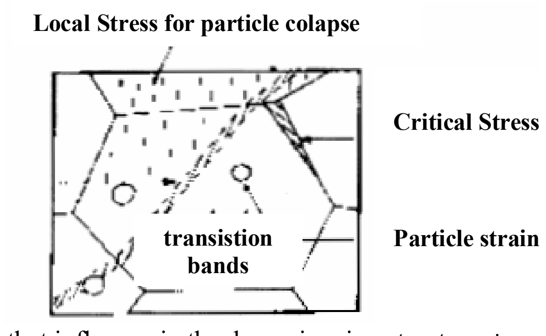

Figure 5: Local events that influence in the dynamic microstructure during the deformation.[13]

4.1 Friction

During the manufacture process, yield and deformation can occur due to the impediment of the free movement between the surfaces, or either, friction. The first study on friction was made using the test of stresses of a ring, where it was verified an increase in the friction with the reduction of the size of the element [8]. The change of friction conditions with the reduction of the size of the element can be determined comparatively. Normally we notice an increase in the friction coefficient with the reduction of the element [5,3,6].

4.2 Temperature

The isothermal heating intervenes with the properties of the material and the friction behavior [8]. It is important to know the gradient of temperature, the average temperature and the maximum temperature to find the definition of the scale factor [3].

$$\Delta T = k_{fm} \varphi / \eta c_p \rho \qquad (1)$$

Properties as the density and the heat capacity can be considered constant. The contact of the tool with the work element is an influential factor in the heating. Although this effect is stronger for microparts, the time of contact of the tool is very low. The temperature field can be calculated assuming a half-infinite solid model, where the thickness does not have influences on the temperature field. However, this model is not valid for very thin samples; in this in case, the temperature gradient will be lower [3].

4.3 Anisotropy

The plastic anisotropy represents the variation of the mechanical properties in function of the direction where the same ones are being measured [11,12]. In metals the most important cause of the plastic anisotropy is the orientation of the grains, or either, the orientation of the crystallographic structure. The anisotropy is important for forming processes; therefore it is responsible for the variation of thickness and the formation of "ears" in the case of deep drawing [11]. High values of anisotropy are preferentially used in order to increase the capacity of deformation in the width with small reductions in the thickness; therefore it means minor plastic instability (figure6).

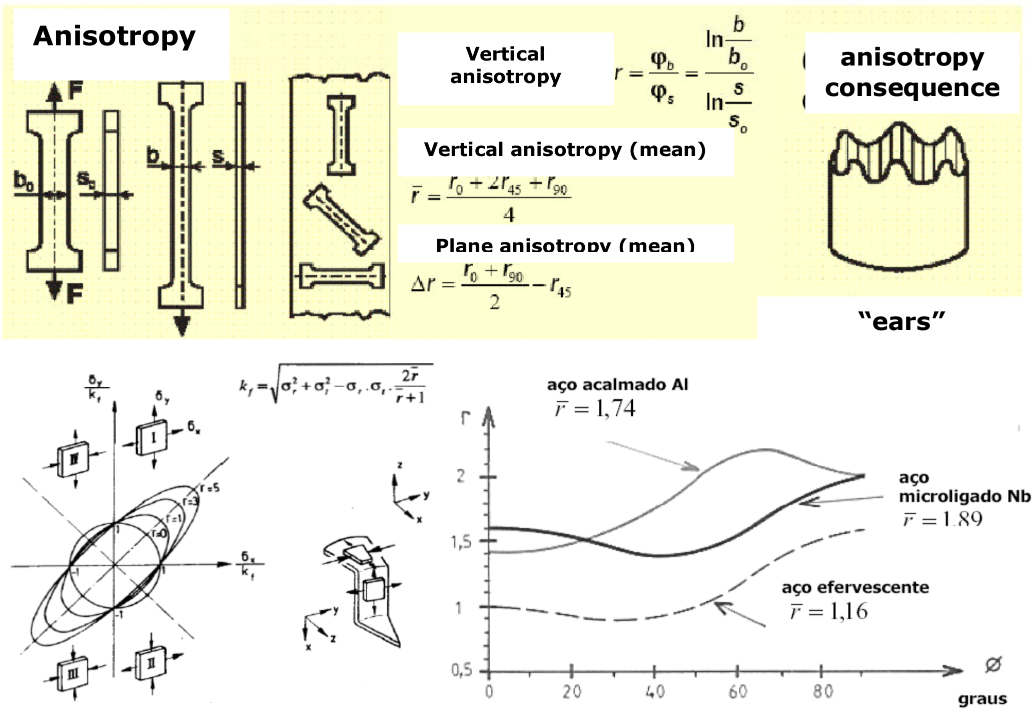

Figure 6: Anisotropy, yield surface (yield locus) and variation with the orientation and type of material and influence of the anisotropy in the format of the height of "ears" formation.

5. Finite Element Method (FEM)

The finite element method is a powerful numerical artifice capable of solving problems related to the physical and mathematical models of the processes of plastic forming of metals. Besides that simulating conditions are very next to the reality, the method can be applied to complex geometric configurations, also considering all the variables as friction and variation of the mechanical properties of the material during the forming process. In this study the softwares LS-Dyna and ADINA were used.

5.1 Assay for analysis of the influence of the scale effect in "springback"

A well usual process in the industry for manufacture of microcomponents is the bending. Figure 7 shows the influence of the mechanical and thermal factors in the microcomponents in processes of bending. Innumerable models exist that conduct the behavior of the part during the bending, however this behavior lose the validity when applied to parts with reduced size. An example is the calculation of the bending force, that arrives to have a shunting line of up to 60% when compared to the experimental results carried through with microcomponents [3].

Another important fact is that the precision of the final product depends strongly on the elastic return ("springback") that is directly dependent on to the grain size of the element and on the effect of present edge in microcomponents. The angle of elastic return decreases with the increase of the grain size, or either, with the increase of the border effect, what can be explained by the easiness to deform plastically that a lesser number of grains in the transversal section has.

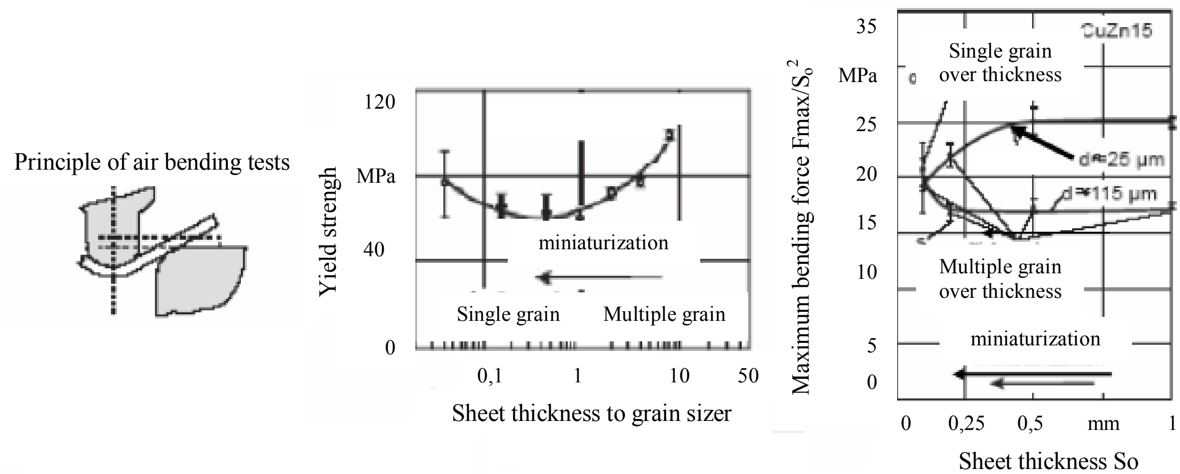

Figure 7: Forces of bending and yield limit: effect of the miniaturization and the grain size. [5]

Some numerical simulations had been carried through that had evidenced the reduction of the angle of elastic return with the reduction of the size of the part; however, comparing the experimental results with the simulational ones, we perceive a small difference.

5.2 The experimental device

A device was developed for some experimental essays. This device had the objective to simulate the bending of a small part in order to evaluate the miniaturization effect. The projected tool should be able to measure the springback angle of the specimen with certain accuracy. This was achieved using a micrometer as the forming tool. The sketch of the tool can be seen in figure9 and the photo of the ready device is in figure 8.

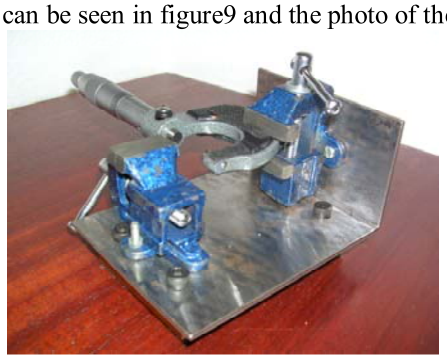

Figure 8: Photo of the device

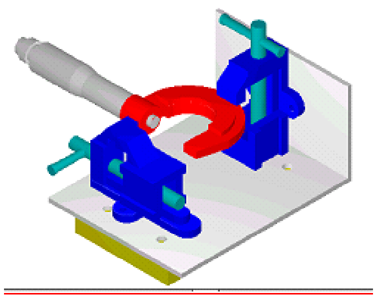

Figure 9: Sketch of the device

With this tool it was possible to perform assays with small and thin parts and also to compare the results with a numerical model for this type of assay. In order to have one better accompaniment of the process and later to carry through more refined measurements of the elastic return; it was created a support, prisoner to the device, that accommodates a digital camera. In the assay, the experiments had been registered at the moment where the largest displacement took place and also when it did not have more the contact with the connecting rod of the micrometer and the sample is free to suffer the elastic return. Figure 10 shows the complete device already with the support for the camera.

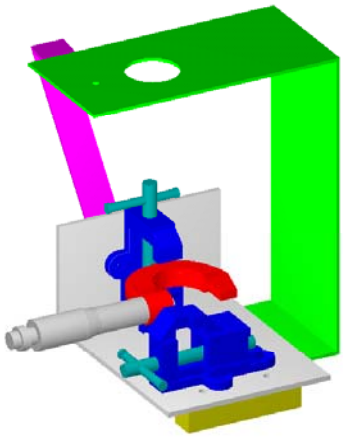

Figure 10: Sketch of the final device

5.3 Test specimens

For this part of the experiments the chosen material was CuZn15, as well as its thickness (0,25 mm). Four different types of samples had been assayed, as shown in figure 11.

Type 1: 14 mm x 11mm x 0,25mm.
Type 2: 14mm x 3mm x 0,25mm.
Type 3: 14mm x 1,5mm x 0,25mm.

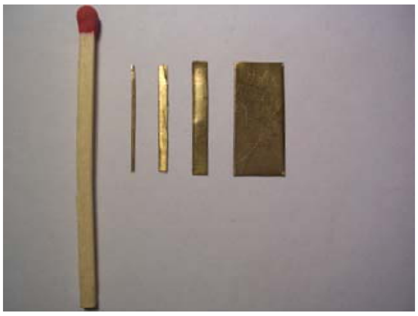

Figure 11: Test Bodies in reduced size

5.4 Experimental assays

It has been assayed four samples of each type of test body. Table 6 shows the results of these experiments.

Table 1: Results for specimens type 1

assay	Spring back (º)for 5 mm	Spring back (º) for 3 mm
1	6,81	5,68
2	6,75	5,74
3	6,78	5,76
4	6,66	5,70
average	6,75	5,72

Analyzing the results, we realize that the reduction of the angle of elastic return with the reduction of the test body really occurred. Some assays have been invalidated due to the high discrepancy with the average results. The biggest difficulty was the attainment of the test bodies in reduced size. They needed to be cut from an entire plate without causing initial deformations in the samples. Another concern was the positioning of the test body in the tool. For validation of the assay, test bodies of other materials had been simulated, like pure nickel and oxygen free copper. The device showed itself efficient, then the results have followed a constant trend and the assays had been of easy accomplishment.

5.5 Numerical simulation - LS DYNA

The analysis of the behavior of the plate when applying the displacement showed an unexpected trend. The plate made a kind of an arc whereas it should deform in a straight direction. This effect was not observed in the experimental assays, as it can be seen in figure 12. The conclusion that we drawn is that the type of element used, or its properties, in the numerical simulation was not the ideal one.

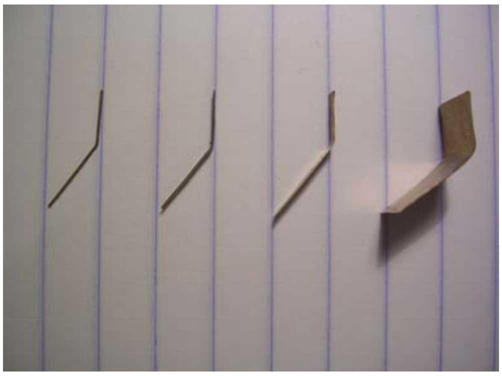

Figure 12: Bodies of test after assay

Figure 13: Numerical simulation

Aiming to correct the discrepancy observed in the comparison between the results of the simulation and the ones from the assays, it was decided to change the element of the material for mat_anisotropic_plastic, where the data of density, modulus of elasticity, coefficient of Poisson and yield stress were necessary. In this type of material the anisotropy was also considered. One more time the mesh took into consideration the dimension of the test specimen in relation to the set as a whole, being different for each one of the bodies. Besides changing the material, the curve of displacement of the forming tool was also modified. In figure 13 we can see an example of the numerical simulation with a better result, very close to the experimental one.

During the numerical simulations it was noticed that it is evident the reduction of the angle of the springback with the reduction of the size of the part, however, comparing the experimental results with the simulated ones we can perceive a clear difference (the assayed parts got a larger springback). Some mentioned factors below are part of possible sources of discord between the simulation and the experimental results.

Material model and element used

Many times the material model used does not adapt itself with the reality of the assay. It was tried to vary these models, however the gotten difference did not justify error in the choice nor of the element nor of the material. The result was also improved when values for the anisotropy were entered, what proves the influence of the size of the element.

Parameters used

The material used has many entrances and can occur that these properties were not in accordance with material properties of the test specimen. This generally occurs when the material used suffered some type of treatment or possess residual stresses proceeding from its production. To try to solve such possible problem the entrance properties were varied, however the results had not demonstrated great alterations. Moreover, some simulations with other types of material had also been made, example: steel and copper without oxygen, the results had however followed the same trend.

Quality control in the accomplishment of the assays

A possible cause for the discrepancy could be some error that occurred during the accomplishment of the assays, as not so many assays have been accomplished, however, as the experimental data followed a certain standard; the probability of such problem is reduced.

Not adequacy of the Software for models with reduced scale

As the majority of the applications of softwares and models related with stamping is used for simulation of forming processes of plates with average sizes, one of the causes for the difference in the results, can be in the method of calculation for elements in reduced scale. Such hypothesis gains force because when the part simulated was smaller; the difference found in comparison to the assay was larger.

7. Conclusions

In this work it is clear the importance of one better understanding of the results for the microforming process. The numerical simulation is becoming an important tool in this direction, but it is still necessary to have a good database regarding the influence of the friction, as well as of the border effect, and the importance of the inclusion of these effects in FEM simulations. The study of the properties of materials, as well as of forming methods, is extremely important for the control of the production of microcomponents. The numerical methods used for the forecast and analysis of conventional manufacture must pass through a great reevaluation to include also the miniaturization effect.

In this context the carried through assays will serve as base of comparison with results of the bibliography and still with numerical results obtained from the FEM simulation. In the simulated results, it can be verified that the miniaturization effect is already perceived, therefore as was waited, the elastic return, springback, was smaller in the smaller components, these results have however not reflected faithfully the results gotten in the assays very probably due to the reasons cited in this paper.

7. References

[1]KOCANDA, A.; PREJS, T. - **The effect of miniaturization on the final geometry of the bent products** – Metal Forming 2000, Proc. of the 8th International Conference on Metal Forming, Rotterdam, A. A. Balkema, 2000, 375-78

[2]GRONOSTAJSTKI, Z. – **Model describing grain size evolution of select copper alloys during and after deformation** - Metal Forming 2000, Proc. 8th International Conference on Metal Forming, Rotterdam, Balkema, 2000, 447- 52

[3]GEIGER, M.; VOLLERTSEN, F.; KALS, R. – **Fundamentals on the Manufacturing of Sheet Metal Micro parts** – Annals of CIRP Vol. 45/1/1996, 277-82

[4]ENGEL, U.; MESSNER, A. **- Numerical simulation of metal forming processes for the production of microparts** – Wire - 2/98, 94-100

[5]ECKSTEIN, R.; ENGEL, U. – **Behavior of grain structure in micro sheet metal working** - Metal Forming 2000, Proc. of the 8th International Conference on Metal Forming, Rotterdam, A. A. Balkema, 2000, 453 – 59

[6]TIESLER, N.; ENGEL, U. – **Micro forming – Effects of miniaturization** - Metal Forming 2000, Proc. of the 8th International Conference on Metal Forming, Rotterdam, A. A. Balkema, 2000, 355 – 60

[7]MICHEL, J.F.; PICART, P. **Size effects on the constitutive behavior for brass in sheet metal forming** J. of Materials Processing Technology 141 (2003) 439 – 46

[8]GEIGER, M.; KLEINER, M.; ECKSTEIN, R.; TIESLER, N.; ENGEL, U. – **Microforming** – Annals CIRP, 50/2/2001, 445 –62

[9]ALTING, L.; KIMURA, F.; HANSEN, H.; BISACCO, G. **MicroEngineering** - Annals CIRP, 52/2/2003, 635-57

[10]MESSNER, A – **Kaltmassivumformung metallischer Kleinstteile – Werkstoffverhalten, Wirkflächen reibung, Prozessauslegung** – Meisenbach Verlag Bamberg; 1997.

[11]BORTOLUSSI R. - **Análise numérica e experimental da hidroconformação de produtos tubulares** - Tese de doutorado; UNICAMP-FEM-DEMA. 2001

[12]CARLEER B. D.- **Finite element analysis of deep drawing**- PhD-Thesis, Univ. of Twente, Netherlands; March 1997

[13]**Textura e relações de orientação - Deformação plástica, recristalização, crescimento de grão –** epusp, dezembro de 2001