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FRICTION STUDIES UTILIZING THE RING - COMPRESSION TEST - PART II

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Summary

With purpose of determining the reliable friction model in experiments of physical modelling of bulk forming processes, with the application of plasticine as modelling material, the series of experiments of free compression of plasticine ring were performed. By varying the kind of modelling tool material and kind of lubricant, according to the experiment plan, the coefficients/factors of friction in modelling experiments with plasticine were determined, by using more kinds of calibration curves shown in the paper (Friction studies utilizing the ring-compression test - Part I). Plasticine, which is used as modelling material, has the static and dynamic characteristics similar to those of most metals and alloys at increased temperatures, so it is used only for modelling of hot bulk forming processes. By obtained experimental results two kinds of lubricants were set apart as adequate in physical modelling of these forming processes. To be precise, talc was selected as lubricant for modelling of hot forming process, for contact surfaces of prepared plasticine and metal surfaces of tool. Vaseline is used as lubricant for minimisation of friction in inter-contact of referent model plane, which is being recorded, and transparent glass tool plate, because vaseline gives the smallest friction coefficient in contact.

Key words: *Contact friction, physical modelling, free ring compression, plasticine*

1. INTRODUCTION

Physical modelling of bulk forming processes is based on substituting real materials with soft modelling materials which have similar behaviour at plastic forming. The application of this method has been increasing for the last few years, both in leading academic and research centres in the world and in large companies which deal with forming problems [1-9]. The results of modelling help the designer and researcher by visualisation of the process in laboratory conditions, by making possible the monitoring of the material flow in referent plane or in the entire model, the monitoring of forming force amount, influence of contact friction in forming zone, appearance of material flow defects and also in verification of results of numerical FEM simulation.

Since modelling materials illustrate the behaviour of real materials in forming realistically, the mechanism and complexity of contact friction conditions are similar. If the modelling material has the dynamic properties similar to those of the real material, i.e. has the similar ratio flow stress-strain-strain rate, the selection of the adequate lubricant is the key problem in physical modelling of the process. There are two methods for establishing the good friction model in physical modelling.

One method involves the investigation of conditions of contact friction of real metal material in process execution conditions which are defined by following factors: tool material, lubricant, piece material, temperature, forming speed etc. A series of experiments with modelling material should be performed for the same process, with more kinds of lubricants which are supposed to give similar friction conditions. The combination metal-lubricant and modelling material-lubricant, which gives the same forming image of flowing, indicates the existence of the same contact conditions, and thus points to the correct selection of modelling lubricant. In this way the selection of adequate lubricant for modelling experiments can be performed by some standard procedures of investigation of contact friction, e.g. methods of divided material flow, monitoring of changes of representative geometrical values of metal samples and modelling material samples. By such qualitative analysis, i.e. visual comparison of metal and modelling samples, formed in the same procedures, the lubricant for physical modelling of the real process is selected, whose application leads to the same geometrical changes of samples.

The second method for selecting the lubricant is quantitative determining of coefficients / factors of friction by application of one of the methods. Direct methods, with use of force or pressure transducer, are rarely used for determining the contact friction in modelling experiments. The reason for that is the imprecision of such a method, because of the appearance of small forces and pressure, due to the small stress of modelling materials flow. The methods of divided material flow, ring test and cigar test methods, are most applied [11]. The fulfilment of condition of similarity of contact friction of real and modelling processes implies the knowledge of values of coefficients/factors of friction in the real process. The proper lubricant for the modelling experiment is the one which gives the same value of coefficient/factor of friction as in the real process.

When complex processes are modelled partially, as entities which are formed more or less in a plane or axis-symmetrically, or if the process is observed or recorded through the transparent tool surface, the contact friction in those planes should be minimised. The existence of contact friction in those planes changes the forming image and the wrong ideas on the process itself are obtained as well as the imprecise modelling results. For the selection of the lubricant, which gives the minimal friction between the modelling material and transparent tool surfaces, it is convenient to use cigar test method for determining the friction coefficient. It is well known that it is sensitive for determining small friction coefficients. Wanheim and Fricker [10] used that method for determining small friction coefficients in modelling experiments with Filia and some of its mixtures, and so did the author of this paper for defining contact conditions in modelling experiments with plasticine [11]. It is emphasised in both papers that vaseline, as a lubricant, gives the smallest values of friction coefficient in modelling experiments; therefore it can be used for lubrication of transparent contact surfaces.

In Metal forming laboratory, at the Faculty of Mechanical Engineering in Kragujevac, plasticine has been used for many years as a modelling material in experiments of physical modelling of various metal forming processes: upsetting, forging, forward, combined and backward extrusion etc [12], [13].

2. DETERMINING OF FRICTION INDICATORS IN MODELLING EXPERIMENTS WITH PLASTICINE

With purpose of obtaining the reliable friction model in modelling experiments with plasticine, the series of experiments of free compression of placticine ring 6:3:2 were performed (ring test) in various contact conditions. In experiments with plasticine the following means are used as lubricants: talc, vaseline, glycerine, Johnson baby powder, teflon, facial tissue, plastic nylon, $CaCO_3$, adhesive paper…[13]. The first three lubricants are most often applied, and they were also used by the author of this paper in his previous researches [12]. The contact friction conditions in modelling experiments do not only depend on the kind of lubricant and the tool surface condition, but also upon the modelling material properties. On the basis of many years experience in application of various kinds of plasticine, the existence of various contact conditions at the application of the same lubricant was also observed. In fact, some plasticines contain the higher percentage of grease and grease acids, so they can absorb the powder lubricants into the surface layer of the model and thus create the disturbances in lubrication, similar to the conditions of contact friction without lubrication. Generally speaking, it is necessary to determine the contact friction conditions for each applied plasticine, i.e. to determine the values of coefficients /factors of friction for those lubricants which are to be used in physical modelling experiments.

The construction of the device for physical modelling, which is used in modelling experiments, is such that the plasticine models are in contact with metal and glass surfaces of the device (see fig. 1). For axis-symetrical models, the glass surface of the tool is on meridian plane of the model, and it enables the recording of the entire process. On such surfaces it is necessary to achieve almost ideal conditions, with no contact friction, i.e. to minimise the friction. This means that it is necessary to select the lubricant whose application provides the smallest value of coefficient/factor of friction at plasticine ring compression. On the other hand, in order to satisfy the conditions of the similarity of model and real process of hot forming of steel, it is necessary to select the lubricant which gives the friction coefficient value which corresponds to those processes. It is believed that, in the hot bulk forming processes, e.g. forging, the contact friction corresponding to friction coefficient range μ=0.3-0.5 is realised.

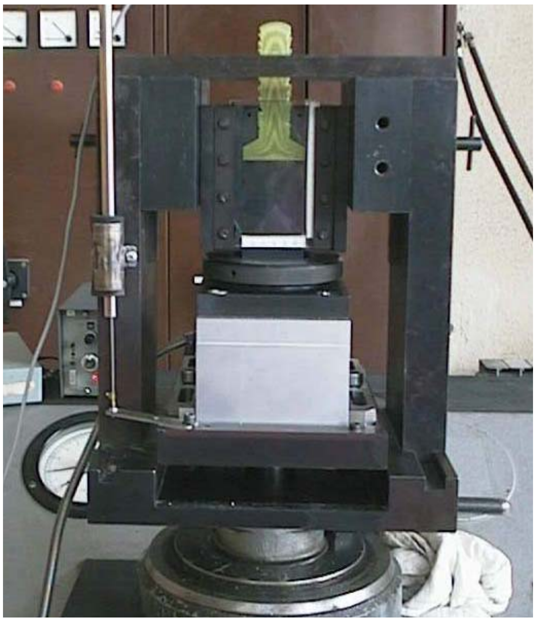

Figure 1.

According to previous considerations, the following combination of contact conditions for experiments of plasticine ring compression was selected: tool material: metal, glass; lubricant: talc, vaseline, glycerine, lubricant mixture (50% vaseline + 50% liquid soap).

The standard ring geometry 6:3:2 was selected, with initial dimension ratio – outer diameter: inner diameter: height = 58 : 29 : 19.3 mm. Previous to that, the plasticine was manually mixing, with purpose of eliminating the air and water holes which appeared in the production process. Handy tools, shaped as thin ring-shaped blade, were used for cutting out the rings out of plasticine plates 19.3 mm thick, obtained by rolling. The rings were compressed between flat parallel plates of the tool, which are the integral part of the device for investigation and physical modelling. The device was assembled onto the hydraulic press type *Erichsen* (see fig.1). The forming speed was constant v_p=10mm/min, and investigation temperature was T=20°C. For each tool-lubricant combination, four rings were compressed up to various percentage shortenings of height, about 20%, 30%, 40% and 50%. In this way the value of coefficients/factors of friction in course of compression was monitored, in many phases, without disturbing the lubrication continuity by inter-phase measurings. The supposition is that all four rings are geometrically identical and with the same layer of lubricant. After completed compression of all the rings, the inner diameters were measured. The relevant value of diameter was obtained as arithmetical mean of two diametrical diameters.

On the following figures some of the experimental results are shown on calibration curves for μ-friction (see fig.2), *m*-friction (see fig.3) and f-friction (see fig.4)

Calibration curves obtained by CAMPform simulation of free plasticine ring compression [14] and some experimental results are shown in figure 5.

3. DISCUSSION

By multiphase ring compression, as is the case here, the change of coefficient / factor of friction in course of compression process is monitored. It is obvious that the increase of realised height strain leads to increase of influence of contact friction, and thus to increase of friction indicator value. At height strains larger than 40-50% the disturbance in lubrication of contact surfaces may occur, due to dislodging of lubricant and creation of initial sticking zones. On the other hand, all indirect methods for determining contact friction, including this one, determine the equivalent values of coefficients/factors of friction without investigating the values of these indicators along the contact surface. However, such equivalent values are usually applied in practice, and the aforementioned mistakes, as well as the influence of anisotropy and bending of sample edges, do not reduce the significance and applicability of obtained results.

For analysis and comparison of equivalent values of coefficients/factors of friction obtained by application of various calibration curves and by use of analytical relations between coefficients and factors of friction, and numerical simulation as well, it is clearer to show the experimental results as a histogram, as in fig. 6.

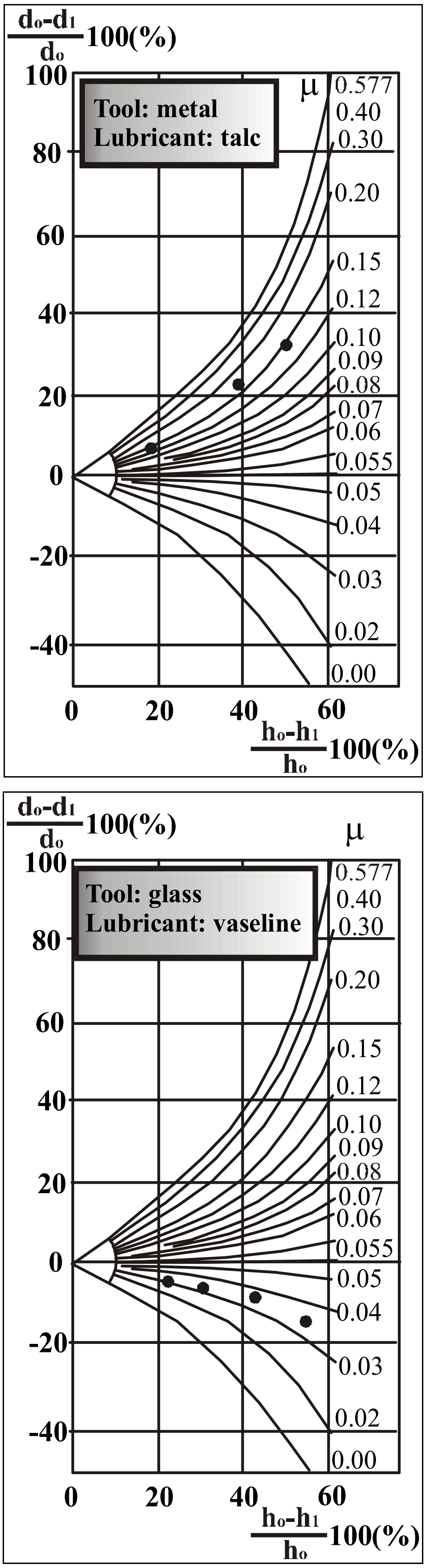

Figure 2-Experimental results, calibration curves Male and Cocroft, μ-friction

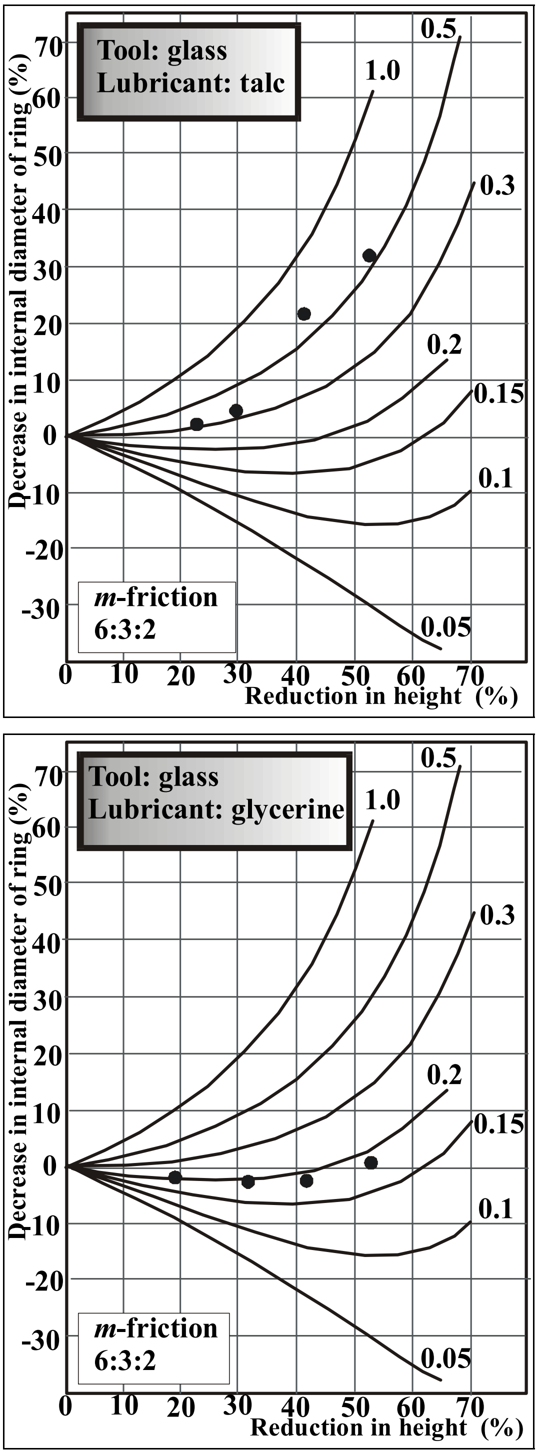

Figure 3-Experimental results, calibration curves Lee and Altan, m-friction

By observing one group of values for any tool-lubricant combination, the smallest values of friction coefficients obtained by application of calibration curves Male and Cocroft are noticed. From a well known relation of friction coefficient μ and friction factor *m*, i.e f [14], the estimated values of friction factor were obtained on the basis of friction coefficient values, marked in values legend as "*Male* m" and "*Male* f". Friction factor values obtained in this way are even twice smaller than values estimated from calibration curves for *m*-friction and f-friction. It has already been emphasised that description of contact friction in bulk forming processes by friction coefficient μ, i.e. μ-friction model is not adequate to the real conditions in inter-contact. In such processes the contact friction is mainly described by friction factor *m* or f, by means of constant friction law or some of the adhesion theories [14].

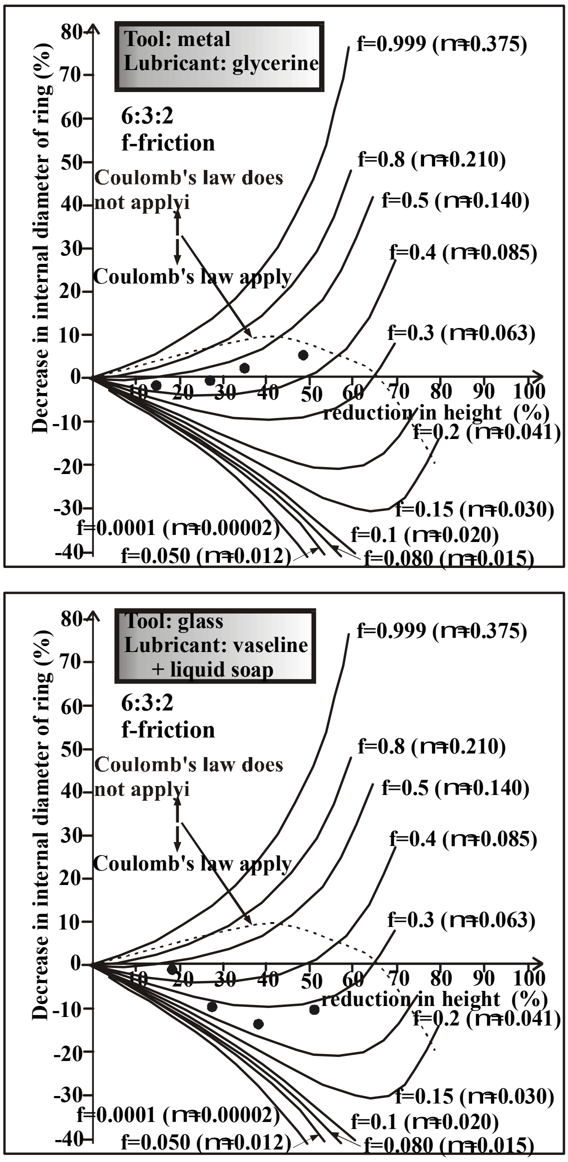

Figure 4-Experimental results, calibration curves Wanheim and Danckert, f-friction

The values of friction factor *m*, determined by use of calibration curves Lee and Altan (see fig.3) and Wanheim and Danckert (see fig.4) are almost identical because the course of curves is almost the same, although the curves were obtained by various approaches in the analysis of ring compression processes. It is interesting that the calibration curves Liu [14], which were obtained by the above estimation method, as well as Lee and Altan curves, are very different, and therefore the friction factor values are very different from the previous ones. The values of these friction factors are almost twice smaller than those determined on the basis of Lee and Wanheim calibration curves, and almost identical to the values obtained on the basis of relations μ→*m* and μ→f. That can be explained by the fact that Liu obtained these curves by taking into consideration the side profile of compressed ring, i.e. barrelling.

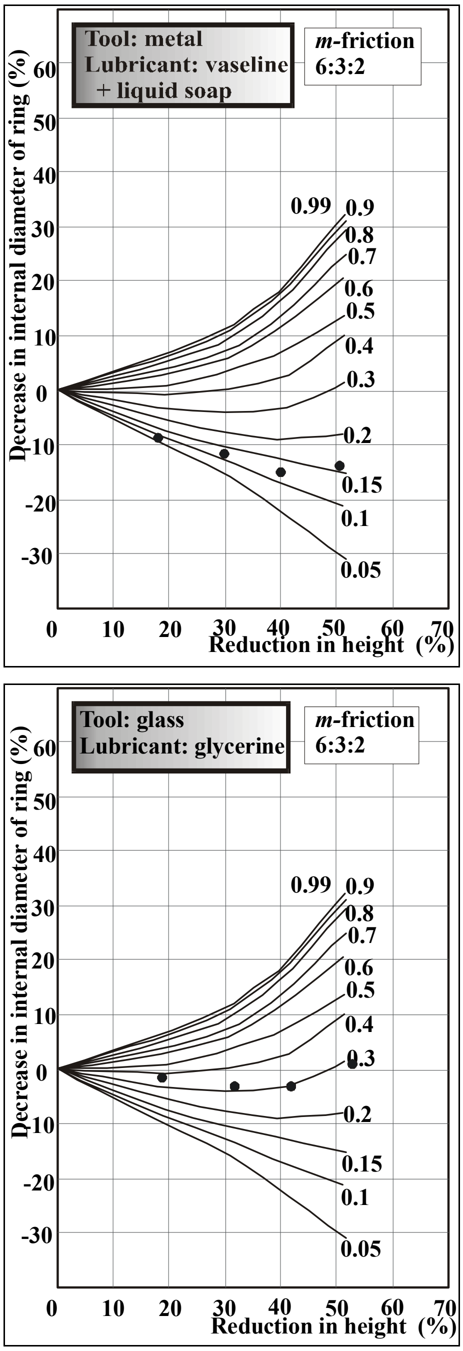

Figure 5 - CAMPform calibration curves for plasticine, and some experimental results

In any case, bearing in mind the results of numerical CAMPform simulation of plasticine ring compression, it is obvious that such small values of coefficients / factors of friction are not compatible to the real situation in inter-contact, at least with regard to plasticine models. For further analysis of results, the values of coefficient *m* obtained by Lee and Wanheim calibration curves will be relevant, as well as the one obtained by new CAMPform curves.

F-friction model, proposed by Wanheim and Bay [14] describes the contact friction in bulk forming processes most realistically, which is confirmed by many literature data. On the basis of their calibration curves, the values of f factor were obtained, which are shown in histogram. However, the commercial FEM program packages, intended for the simulation of bulk forming process, mainly use *m*-friction model, while, as far as the author of this paper is informed, the f-friction model is not present. The program PLAST 2, developed at the Institute for material forming in Denmark [15] is the exception. In that way, the program CAMPform, which is used in the paper, was developed on the basis of *m*-friction model.

By the numerical simulation of plasticine rings compression the calibration curves were obtained, and on the basis of them the values of friction factor. These values “lie” between the *m* factor value (Lee and Wanheim) and f factor. Since the simulation of the hot bulk forming process is performed by application of FEM program CAMPform, the author finds it logical to adopt the values of friction factor obtained by application of new CAMPform calibration curves.

Regarding the fulfilment of the condition of similarity of contact friction in real hot forming processes and physical modelling of these processes, talc will be used as the lubricant. Friction coefficient in these processes is in 0.3-0.4 range, which corresponds to the application of this lubricant in modelling experiments. On the shown histogram, the values of friction coefficient μ, obtained by analytical dependence μ→f, on the basis of factor f are μ=0.3 for metal-talc combination. For lubrication of contact glass tool surfaces with plasticine, vaseline (μ=0.063, f=0.3, and m=0.2) or lubricant mixture of vaseline and liquid soap (μ=0.06, f=0.28, i m=0.2), can be used as lubricants, which minimises the influence of contact friction onto the plastic flow of material. In practice, it is much easier to use pure vaseline as lubricant, because the mixtures of vaseline have to be weighed precisely and mixed well in

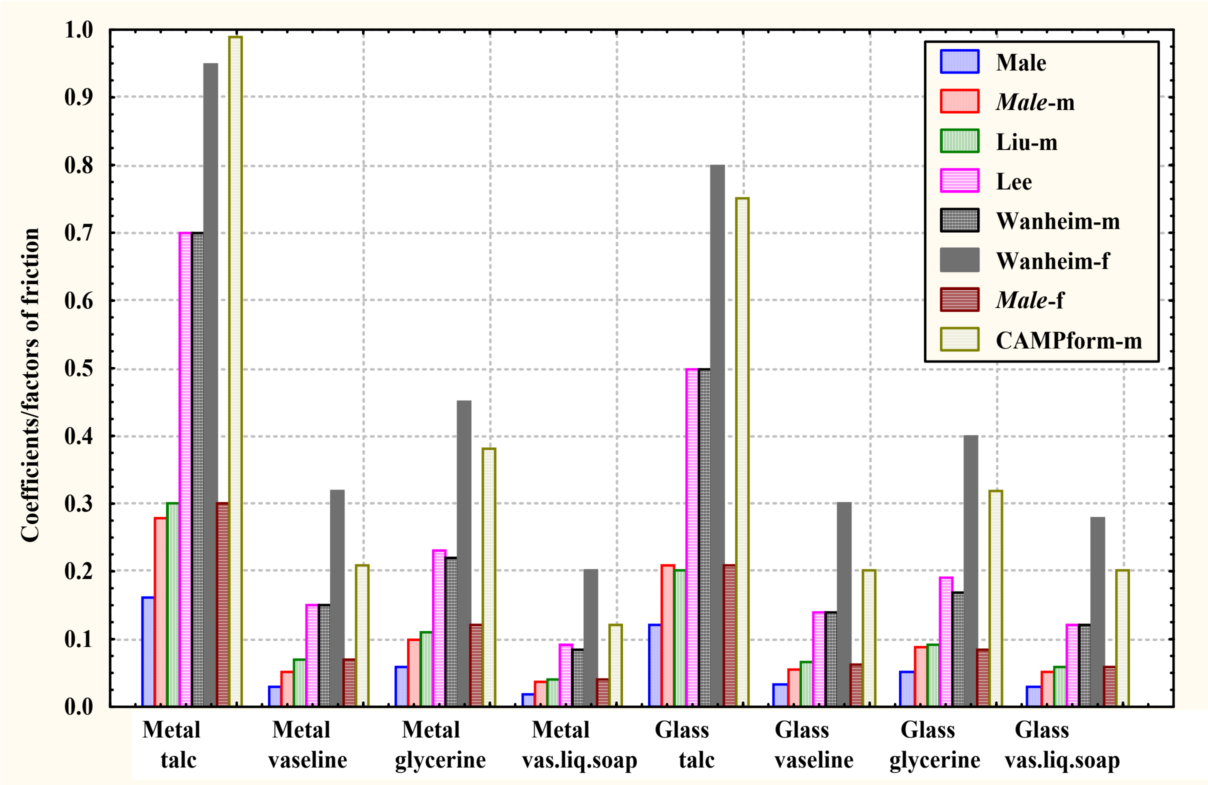

Figure 6 - Comparative histogram of values of coefficients/factors of friction

order to obtien the well integrated components and the same lubrication conditions on the entire contact surface.

4. CONCLUSION

At physical modelling of bulk forming processes by application of modelling materials, the selection of the adequate lubricant is the crucial step, and it must be performed carefully. The results of modelling and their transfer onto the real processes highly depend upon the similarity of contact friction conditions in modelling and real process.

The performed series of experiments of free plasticine ring compression showed that talc is the adequate lubricant in modelling of hot bulk forming processes with application of plasticine models. The model surfaces which are in contact with transparent tool parts, where it is necessary to minimise friction, can be lubricated with vaseline or lubricant mixture (50% vaseline and 50% liquid soap). Considering the problem of non-homogeneity of mixture structure, it is much easier to use pure vaseline as lubricant.

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