Effect of different contact formulations used in commercial FEM software packages on the results of hot forging simulations

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Commercial FEM-software packages are widely used in the industry to predict material flow, temperature distribution and die load during the forging process. Contact in conjunction with plastic material behaviour, which is typical for forging simulations, leads to highly nonlinear equations in the FEM algorithms, which may cause problems in numerical convergence. Some FEM software providers handle this problem by automatic contact damping or similar algorithms. However, the user has mostly no detailed information about adjustments and prediction accuracy. The only possibility for the user to have an impact on the contact behaviour is to set a friction factor and to choose a friction model (e.g. Coloumb or Shear) appropriate to the investigated process. Friction factors are often measured by standard tests like the ring compression test which should be valid for all used software packages. In this paper a benchmark between three software programs is performed based on a model for ring compression tests under typical hot forging conditions. The commercial FEM-software programs Deform2D, Forge2007 and Abaqus are compared by generating a nomogram for each software package. For all simulations identical physical (temperature, flow curves etc.) as well as numerical influence parameters are used. The simulations show a significant divergence in the results depending on the used FEM-software. This leads to the conclusion that a friction coefficient which is true for one software package can not be transferred directly into another one.

KEYWORDS:
Ring Compression Test, Contact, Friction, FEM Simulation, Abaqus, Deform, Forge

INTRODUCTION

Friction is a major factor in determining the characteristics of metals as they are formed. In forging, friction is a key factor in the pattern of metal flow and die wear. In general, excessive friction has a negative influence on die wear, product quality, product cost, and productivity. It is therefore common to use various lubricants to reduce friction during metal forming operations. Major factors affecting friction include the normal stress along the die–material interface, the lubrication condition, the relative velocity, the temperature, the roughness and the mechanical properties of the material and/or the die. A detailed investigation of these factors is not easy because the die–material interface in metal forming is under high pressure and temperature. Thus, friction in this area is still somewhat of a mystery even though many researchers have performed detailed studies in various ways for a long time [1-10].
In metal forming simulations, friction has traditionally been assumed to follow the Coulomb friction law or the constant shear friction law [1-5]. In the last years hybrid friction models like the model proposed by Wanheim and Bay [6,7] became more crucial in FEM simulations. Contact in conjunction with plastic material behaviour, which is typical for forging simulations, leads to highly nonlinear equations in the FEM algorithms, which may cause problems in numerical convergence.
Some FEM software providers handle this problem by automatic contact damping or similar algorithms. However, the user of commercial FEM-software has mostly no detailed information about adjustments and prediction accuracy. The only possibility for the user to have an impact on the contact behaviour is to set a friction factor and to choose a friction model appropriate to the investigated process and the tribological conditions that occur during forging.

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THE RING COMPRESSION TEST

The ring compression test [8] is a commonly used experimental method for the determination of the frictional conditions in bulk metal forming for a given combination of tool, material and lubricant.
Compression of rings offers the great advantage that the frictional conditions can be judged from the deformation of the ring shaped sample [5]. The coefficient of friction is related to the change in inner diameter produced by a given amount of compression in the thickness direction. To obtain friction values for FEM – simulations the experimental values are to be compared with calibration curves determined from a series of simulations with different friction conditions. Fig. 1 shows an example for such a calibration curve generated in Abaqus/Standard. The comparison with the experimental result (dashed line) gives a friction coefficient of 0.2 to be set in the simulation.

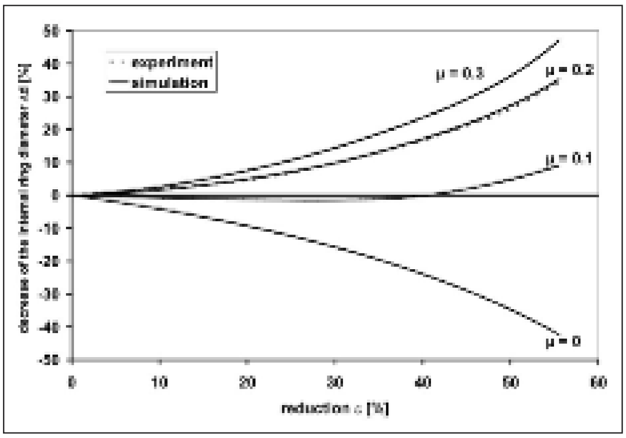

FIG. 1 ***Calibration curve obtained from FEM – simulation with Abaqus/Standard compared with a result obtained from experimental investigations.***

Curve di calibrazione ottenute mediante simulazione FEM con Abaqus/Standard confrontate con un risultato ottenuto da indagini sperimentali.

THE SIMULATION MODEL

The present work shall give an answer to the question whether the friction coefficient which has been developed for one software package can directly be assigned to another one. For this purpose a ring compression test has been modeled in the three implicit FEM codes, namely Abaqus/Standard, Deform2D and Forge2007. The input parameters for all three software packages are the same (Table 1) and the friction coefficient between the ring and the die is varied between μ = 0 and μ = 0.5 using Coulomb friction. In all cases an isothermal axisymmetric 2D - model with additional radial symmetry is used (fig. 2). In Abaqus/Standard and Deform2D quad - elements are implemented while in Forge2007 it is only possible to use triangles. The die is implemented as a rigid object. The decrease of the internal ring diameter after deformation is calculated by equation 1.

$$\Delta d = \frac{d_{i0} - d_{i1}}{d_{i0}} \cdot 100\,, \qquad (1)$$

RESULTS

Fig. 3 shows the computed geometry of the compressed rings for a reduction value of 50%. The initial inner and outer diameters of the sample are marked with a dashed line. It is obvious from the simulation results that the inner diameter is much more sensitive to friction coefficient changes than the outer diameter, which is the reason that in experimental ring compression tests only the inner diameter of the ring is analyzed [2-10]. For friction μ = 0 all three software packages show that no bulging of the specimen occurs during compression and the inner as well as the outer diameter increases. A friction value of μ = 0.05 also leads to an increase of the inner and the outer diameter.

The material flow outwards together with the friction at the contact surface with the die leads to concave bulging of the inner surface of the sample. The outer surface shows a convex bulging. The geometry obtained from the three solvers is nearly the same for this case. The next higher friction value investigated in the simulations (μ = 0.1) already results in a decrease of the inner diameter and consequently the inner contour bulges convex. For this friction value the three programs also compute very similar shapes for the specimen. Contrary to this behaviour a significant deviation in the resulting shape of the sample can be observed for μ = 0.15 (fig. 4). The computed inner diameter of the ring for this friction value is 10.18 mm in Deform2D, 11.58 mm in Abaqus/Standard and 12.06 mm in Forge2007, which gives a deviation of 1.88 mm between Deform2D and Forge2007. For friction μ = 0.2 (fig. 5) the inner diameter is 8.8 mm in Deform2D, 9.96 mm in Abaqus/Standard and 10.46 mm in Forge2007. The deviation between Forge2007 and Deform2D decreases to 1.66 mm. The computed inner diameters for μ = 0.3 (fig. 6) are 8.18 mm for Deform2D, 7.82 mm for Abaqus/Stan-

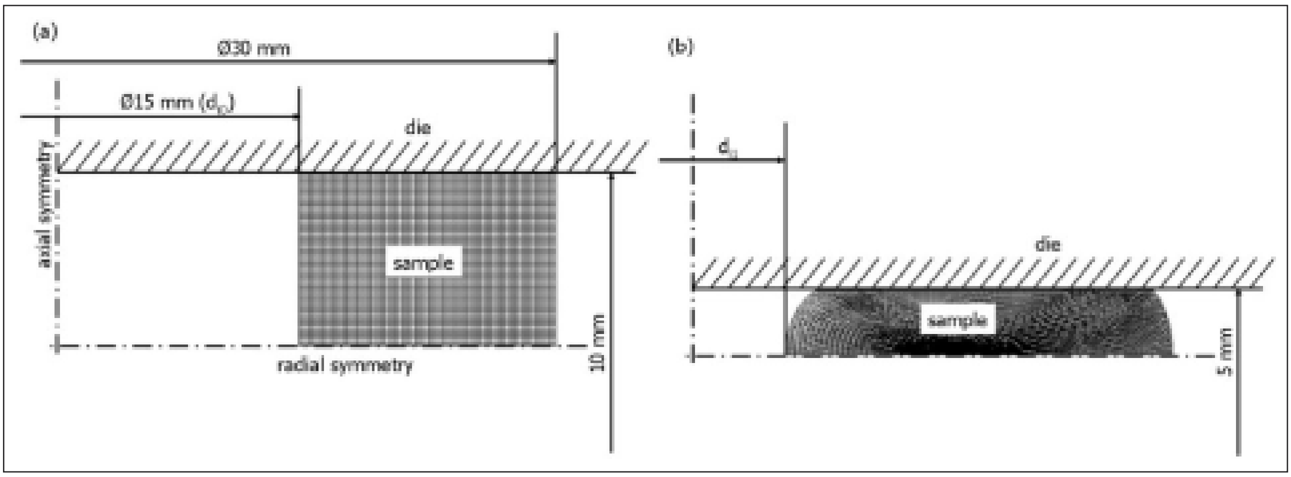

FIG. 2 ***FEM – model of the sample before (a) and after (b) compression for μ = 0.5.***

Modello di simulazione FEM del provino prima (a) e dopo (b) compressione con μ = 0.5.

Specimen's shape	See fig. 2
Sample material	Steel, 42CrMo4; Flow curves acc. to Doege [11]
Sample temperature	1200 °C
Element length	0.1 mm
Element type	2D Axisymmetric, reduced integration
Die speed	10 mm/s

TAB. 1 ***Most relevant input parameters for the simulations.***

Principali parametri di ingresso utilizzati nella simulazione.

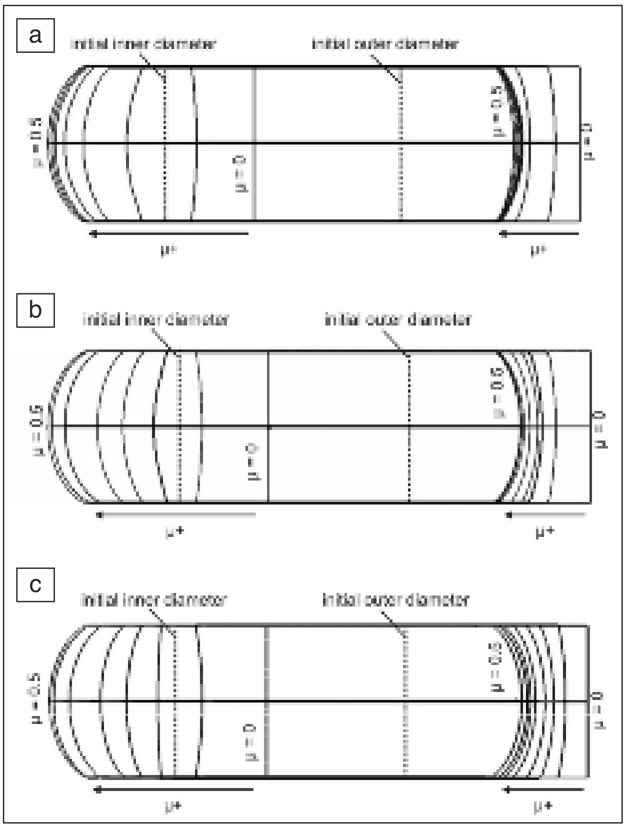

FIG. 3 ***Geometry of the samples for a reduction value of 50% and the investigated friction values (μ = 0, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5) obtained from Deform2D (a) Abaqus/Standard (b) and Forge2007 (c).***

Geometria dei provini per un valore di riduzione del 50% e valori di attrito imposti (μ = 0 - 0,05 - 0,1 – 0,15 - 0,2 – 0,3 – 0,4 – 0,5) ottenuti mediante Deform2D (a) Abaqus/Standard (b) e Forge2007 (c).

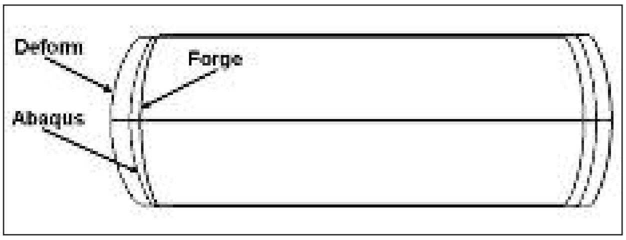

Fig. 4 ***Geometry of the sample for a reduction value of 50% and friction μ = 0.15 obtained from Deform2D, Abaqus/Standard and Forge2007.***

Geometria del provino per un valore di riduzione del 50% e attrito μ = 0,15 ottenuta mediante Deform2D, Abaqus/Standard e Forge2007.

dard and 8.24 mm for Forge2007. At this friction value the largest deviation is between Forge2007 and Abaqus/Standard and decreased to a relative low value of 0.42 mm. For higher friction values the deviation of the results stay in this small range and for μ = 0.5 the computed contour is nearly the same for the different FEM codes.

The calibration curves obtained from the simulations (fig. 7a, b and c) reflect the results from the geometrical investigations above. The basic characteristic of the graphs is the same for all three investigated FEM solvers. Low friction (μ < 0.1) leads to an increase of the internal diameter of the specimen (negative va-

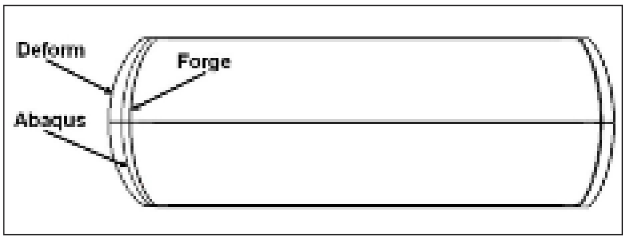

FIG. 5 ***Geometry of the sample for a reduction value of 50% and friction μ = 0.2 obtained from Deform2D, Abaqus/Standard and Forge2007.***

Geometria del provino per un valore di riduzione del 50% e attrito μ = 0,2 ottenuta mediante Deform2D, Abaqus/Standard e Forge2007.

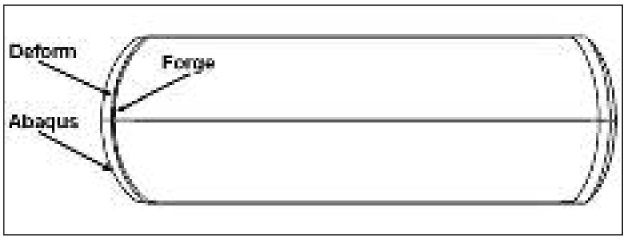

FIG. 6 ***Geometry of the sample for a reduction value of 50% and friction μ = 0.3 obtained from Deform2D, Abaqus/Standard and Forge2007.***

Geometria del provino per un valore di riduzione del 50% e attrito μ = 0,3 ottenuta mediante Deform2D, Abaqus/Standard e Forge2007.

lues of d). Higher friction values result in a decrease of d. This behaviour is typical for ring compression tests and is well documented in calibration curves obtained from analytical approaches [8-10] as well as simulation studies [2-7]. The curves give nearly the same values for low friction (μ < 0.1). High friction values (μ > 0.3) also lead to similar values in all three solvers according to the small deviations for the inner sample diameters as described above. The largest deviations in geometry and consequently in the calibration curves occur for medium friction values. To illustrate the deviation, fig. 7d shows the value for d as a function of the friction coefficient at a reduction value of 50%. From this curve and from fig. 3a it becomes clear that a change in friction from μ = 0.3 to μ =0.4 has only small influence on the simulation result obtained from Deform2D while Abaqus/Standard and Forge2007 are more sensitive on changes on friction coefficient in this range. Changing the friction from μ = 0.4 to μ =0.5 has only a small influence on the simulation result for all investigated programs. Furthermore from fig. 7d it can be followed that a friction value of e.g. μ = 0.2 which has been calibrated for Forge2007 gives the same result than μ = 0.18 in Abaqus/Standard and μ = 0.14 in Deform2D for the specific investigated case here. Hence these medium friction values for which the largest deviations occur are typical for lubricated hot forging it can be followed that experimental results must always be calibrated in the simulation software for which they are used for to prevent significant computation errors.

The computed die load shows similar values for Deform2D and Forge2007, while the maximum load obtained from Abaqus/Standard simulations is about 20% higher. The load-stroke curve obtained from Deform2D (fig. 8a) shows significant oscillations for friction coefficients higher than μ = 0.1 which leads to a degree of uncertainty when comparing the die load at a reduction value of 50%. Nevertheless, fig. 8d shows the ge-

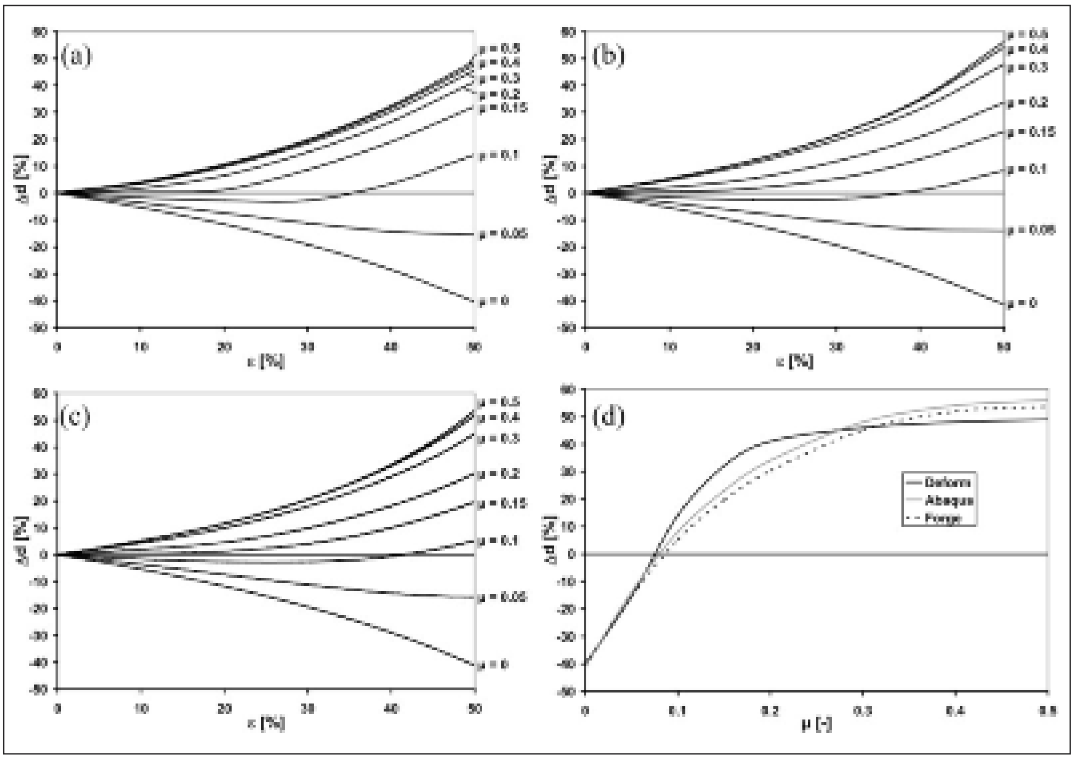

FIG. 7 ***Calibration curves obtained from Deform2D (a), Abaqus/Standard (b), Forge2007 (c) and d as a function of μ for a reduction value of 50%.***

Curve di calibrazione ottenute mediante Deform2D (a), Abaqus/Standard (b), Forge2007 (c) e d in funzione di μ per un valore di riduzione del 50%.

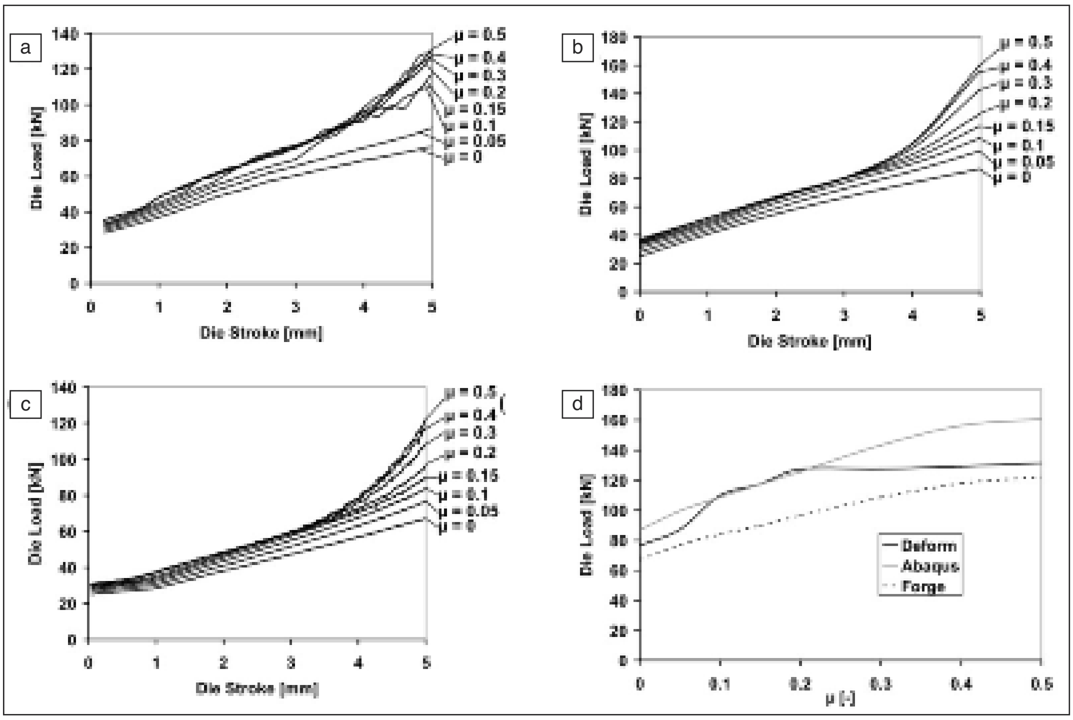

FIG. 8 ***Load-stroke curves for the die obtained from Deform2D (a), Abaqus/Standard (b), Forge2007 (c) and die load as a function of μ for a reduction value of 50% (d).***

Curve dii carico-corsa per lo stampo ottenute mediante Deform2D (a), Abaqus/Standard (b), Forge2007 (c) e carico dello stampo in funzione di μ per un valore di riduzione del 50% (d).

neral trend that the load obtained from Forge2007 is the lowest while Abaqus/Standard computes the highest load for all investigated friction factors. At this point it must be mentioned again that the mechanical input data (flow curves) as well as the mesh size is kept constant for all computations performed in this work.

CONCLUSION

The presented study shows that different contact algorithms in commercial FEM software packages lead to different results in forging simulations even though all other input parameters are kept constant. The most significant deviations occur for friction coefficients between $\mu = 0.1$ and $\mu = 0.3$ which is a typical range of friction for hot forging. This is not a statement concerning the quality of the contact algorithms in a specificprogram but the study shows that a friction coefficient which is true for the usage with one software package is not automatically suitable for another one. Hence, it must be concluded that the friction coefficient has to be calibrated for each process and software package used for simulation. The calibration curves achieved from this study were generated under the pre-condition that only friction is changed and all the other parameters are the same for all simulations. To ensure this, all simulations were performed with isothermal data. Since temperature distribution in the specimen has a significant influence on the material flow during bulk forming the curves presented here can not be used to calibrate actual experiments.

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Abstract

Effetto delle diverse formule di contatto utilizzate nei software commerciali FEM sui risultati della simulazione della forgiatura a caldo

Parole chiave: forgiatura – acciaio – simulazione

I software commerciali di simulazione FEM sono ampiamente utilizzati nell'industria per predire il fluire del materiale, la distribuzione della temperatura e il carico dello stampo durante il processo di forgiatura. Il contatto insieme al comportamento plastico del materiale, che è tipico nelle simulazioni di forgiatura, porta ad equazioni fortemente non lineari negli algoritmi FEM, e ciò può causare problemi di convergenza numerica. Alcuni fornitori di software FEM risolvono questo problema mediante algoritmi automatici per l'ammortamento del contatto o algoritmi simili. Tuttavia, l'utente nella maggior parte dei casi non riceve informazioni dettagliate sugli adattamenti e sulla precisione della previsione. L'unica possibilità dell'utente di influire sul comportamento a contatto consiste nell'impostare un fattore di attrito e di scegliere un modello di attrito (ad esempio Coloumb o taglio) che siano adeguati al processo di indagine. I fattori di attrito vengono spesso misurati mediante prove standard, come la prova di compressione ad anello che dovrebbe essere valido per tutti i software utilizzati. In questo lavoro viene eseguita una comparazione tra tre programmi software sulla base di un modello per prove di compressione ad anello (ring compression test) in condizioni tipiche di forgiatura. Vengono confrontati i programmi commerciali FEM-Deform2D, -Forge2007 e -Abaqus generando un nomogramma per ogni software. Per tutte le simulazioni sono stati utilizzati identici parametri fisici (temperatura, curve di flusso, ecc), nonché parametri numerici che possono influire. Le simulazioni mostrano una significativa divergenza tra i risultati a seconda del software FEM utilizzato. Ciò porta alla conclusione che un coefficiente di attrito che risulta essere adatto per un software non può essere trasferito direttamente in un altro.