ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XVIII [2020] | Fascicule 1 [February]

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665

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DETERMINATION OF FRICTION COEFFICIENT WITH CONICAL TUBE UPSETTING TEST FOR COLD FORMING PROCESS

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Abstract: The main objective of this research was to determine and verify friction coefficient using conical tube upsetting test for cold upsetting process with oil lubrication. Chosen material for conical tube is steel C45E. For experimental setup two types of conical tubes were used: conical tubes with cone angle of: 8˚ 30' and 15˚. After the upsetting, change in height and outer diametar of specimens is measured. Required calibration curves for estimation of friction coefficient are provided by finite element (FE) simulation of the process. For the simulation of the process Simufact.forming 12 software is used. By comparison of experimental results and calibration curves it is concluded that the friction coefficient of μ = 0.095 agrees the most with both types of specimens. Estimated value of friction coefficient is verified by comparison of force – stroke (F–s) diagram and characteristic dimensions of specimens from numerical simulation for estimated coefficient and experimental results.
Keywords: friction coefficient, cold upsetting, conical tube, calibration curves

1. INTRODUCTION

In bulk metal forming processes, friction between tool and workpiece have a significant influence on most process variables, such as material flow, deformation load and surface quality. Because of the difficulties that occur during direct measurement of friction stress, several experimental setups based on measurement of a friction sensitive values were proposed. Some of the most commonly used methods are the ring compression test, the combined forward–backward extrusion, the forward bar extrusion, the T – Shape compression and the backward – forward hollow extrusion [1], [2].
Conical tube upsetting test was developed by Kopp and Philipp [3] as an improvement of commonly used ring test for estimation of larger values of friction coefficient, like one that occur in hot forming processes [4]. The main advantage of this methode is the freedom of choice of the cone angle. By choosing the appropriate cone angle, it is possible to achieve almost homogeneous relative velocity in the outer radial direction between the die and the specimen with no sticking friction. Also, the sensitivity of the test to different values of friction coefficients could be increased by using specimens with the suitable cone angle. Larger cone angle will provide better sensitivity of the test to higher friction coefficients and vice versa. It is recommended to use the specimens with cone angle from 10° to 20°, except for dry forming of aluminium specimens, in which case the better sensitivity of the test is achieved using the specimens with cone angle up to 30° [5], [6]. Compared to the other tests for friction determination, main disadvantages of this test are: reduced contact stresses, lower strains, higher production costs for specimens and tools, and influence of alignment between die and specimen on axial symmetry of the specimens after the upsetting [4].
In this test, the outer diameter of the specimens conical surface represents friction sensitive value. Before and after the upsetting process, the height and the outer diameter are measured and the relative change of dimensions is calculated. Comparing the experimental result with calibration curves obtained from FE simulation it is possible to determine the friction coefficient [3].

The aim of this research was to determine and verify the value of friction coefficient for cold metal forming process with oil lubrication for the material of specimen carbon steel C45E. The expected value of friction coefficient in defined conditions varies from 0.08 to 0.15 [7]. The entire procedure of the determination of friction coefficient, and later verification is schematically presented in the flow chart in Figure 1.

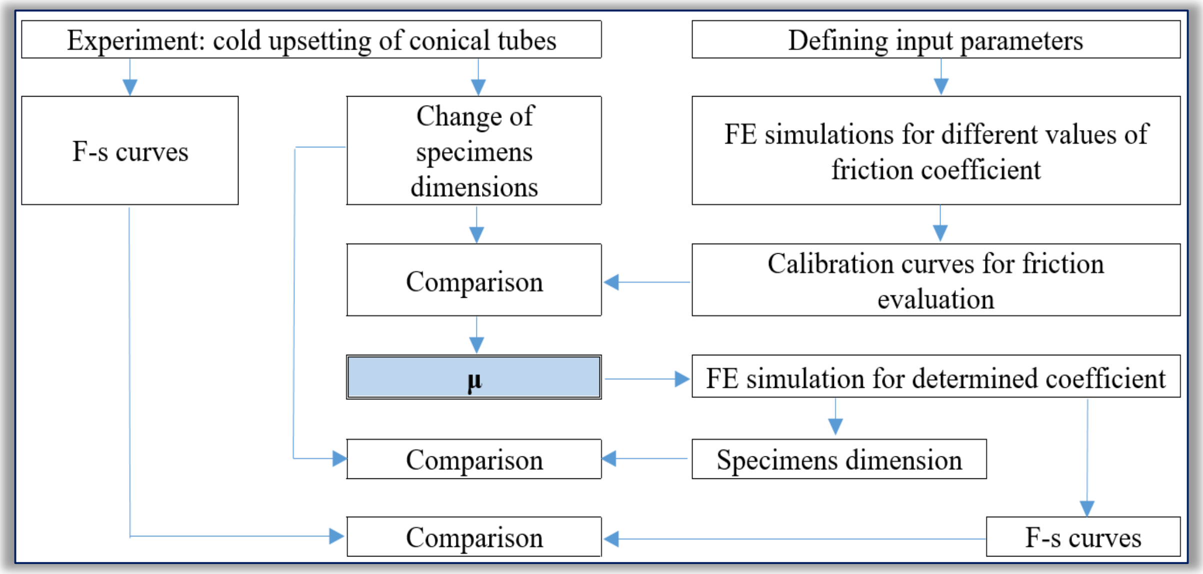

Figure 1. Flow chart of the determination and verification of friction coefficient

2. DETERMINATION OF THE FRICTION COEFFICIENT

Experimental work consists of the upsetting of conical tubes with a cone angle of 8°30' and 15° with stationary upper conical die and moving lower flat die. Five specimens from each type were used to evaluate and verify the friction coefficient. By upsetting five specimens with different stroke instead of incrementally upsetting one specimen, necessary relubrication of contact surfaces and damage of initial lubrication regime is avoided. Hence, determination and verification of the friction coefficient should be more accurate. Stroke was increased from 1 mm, for the first specimen, to 5 mm, for the last specimen, in 1 mm steps.

Specimens before and after the upsetting are schematically presented on Figure 2. The initial outer diameter D_0 of both types of specimens was 20 mm and the inner diameter d_0 was 10 mm. Initial height h_0 of specimens with a cone angle of 8°30' was 10 mm, while the height of specimens with a cone angle of 15° was 15 mm (Figure 2.). After the upsetting, outer diameter D_1 and height h_1 of specimens were measured. Calculated relative change of dimensions is then used to evaluate coefficient by comparison with calibration curves from FE simulation.

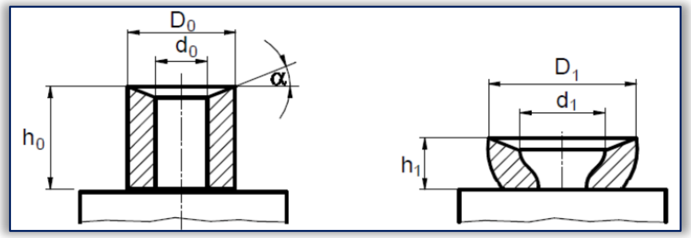

Figure 2. Specimen geometry in conical tube upsetting test [4]

For the upsetting of conical tubes, hydraulic press Sack&Kisselbach with a nominal force of 6.3 MN was used. Upsetting speed was 1 mm/min and the experiment was conducted on room temperature. The material of specimens was carbon steel C45E.

For lubrication of flat surface stearic acid was used, while for the conical surface "Modriča" oil for cold metal forming was used. It is assumed that the lubricant on the conical surface is uniformly distributed and the layer has the same height on every specimen. Before the lubrication, contact surfaces were cleaned with alcohol.

Calibration curves for the conical tube upsetting test, due to the complexity of specimens geometry, could only be determined using FE simulation software. By using Simufact.forming v12 software, FE simulations of the upsetting process were performed for different values of friction coefficient in order to form calibration curves for friction evaluation. The geometry of dies and specimens was modeled in SolidEdge V18 and imported in Simufact.forming. To reduce the time of the simulation, 2D axisymmetric FE models with elements type quad were used. Element size was 0.16 mm, which resulted in approximately 1600 elements for specimens with a cone angle of 8°30' and 2400 elements for specimens with a cone angle of 15°. Material flow curve was measured within a laboratory using Rastegaev specimens.

On Figure 3.a. and Figure 4.a. comparison between experimentally measured relative change of specimens dimension with calibration curves for different values of friction coefficient gained from FE simulation is presented. As experimental results indicate that the value of the friction coefficient is between 0.05 and 0.1, additional simulations were performed for the exact same range. It can be observed that for both types of specimens, the best overlap of experimental and simulation results is achieved for the friction coefficient of 0.095 (Figure 3.b. and Figure 4.b).

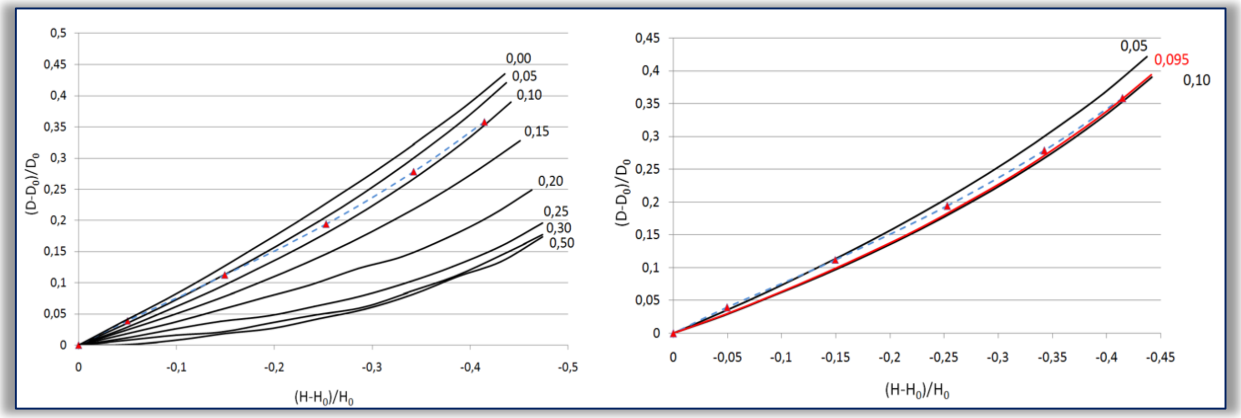

Figure 3. Determination of friction coefficient using specimens with a cone angle of 8˚ 30’

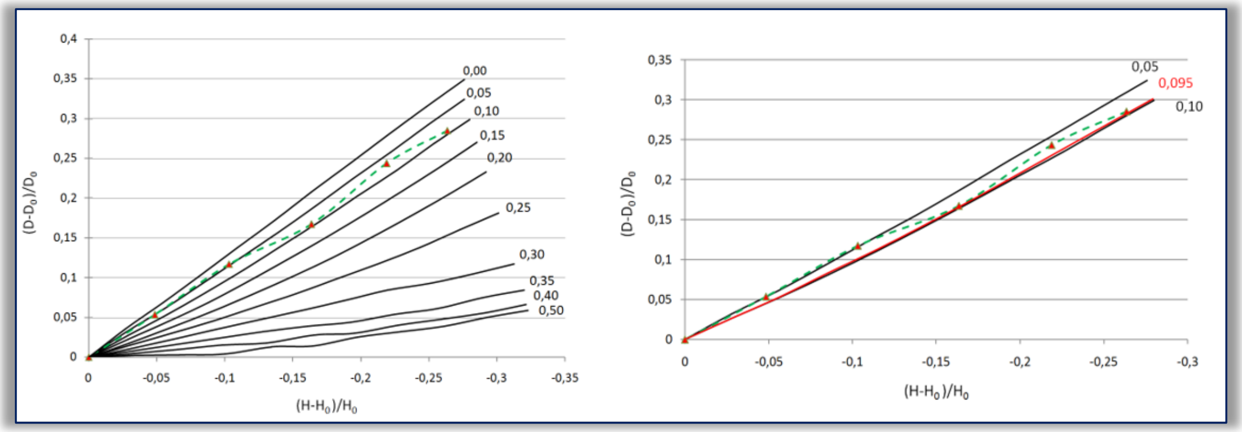

Figure 4. Determination of friction coefficient using specimens with a cone angle of 15˚

3. VERIFICATION OF THE FRICTION COEFFICIENT

— Comparison of F–s curves

High contact pressure that can go up to 2500 MPa, plastic deformation and the change of contact area during metal forming process cause high friction forces on contact surfaces of the dies and specimens. Since the friction forces in some metal forming process could reach almost 40% of total deformation force, comparison of F–s curves between the experiment and simulation for determined coefficient should give good verification of the result [7], [8].

To measure F–s curve, both types of specimens were upset until the first crack occurred. Specimens with a cone angle of 8°30' reached 6.5 mm stroke, while for specimens with a cone angle of 15° cracking occurred for the reached stroke of 6 mm. Measuring equipment consisted of 8 channel amplifier Spider8, HBM transducers for stroke and pressure W20 ±50mm and P3M 500bar, and software package Catman Easy. For comparison, another FE simulation was performed for the determined value of friction coefficient and reached value of stroke for both types of specimens. Comparison between experimentally measured F–s curve and curve as a result of FE simulation for 8°30' specimens is presented on Figure 5 and for the specimens with a cone angle of 15° on Figure 6. On Figure 5 it can be observed that the slopes of both curves are very similar. To compare both curves maximum and average deviation was calculated. The maximum deviation of the experimental curve from the simulation curve was 7.9%, for 4.5 mm stroke, while the average deviation was just 3.77%.

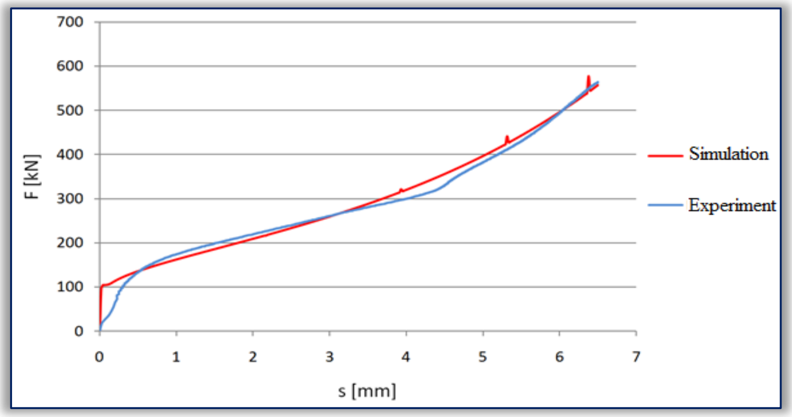

Figure 5. Comparison of F–s curves for specimens with cone angle 8°30'

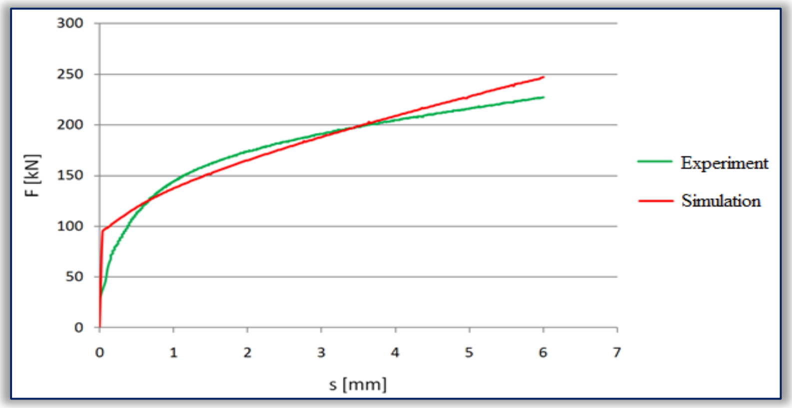

Figure 6. Comparison of F–s curves for specimens with cone angle 15°

From Figure 6 it can be observed that the experimental and simulation curves for specimens with a cone angle of 15° have a similar trend. The maximum deviation of the experimental curve from the simulation curve was approximately 8%, for 6 mm stroke, while the average deviation was only 4.24%.

Since for both types of specimens maximum deviation of F–s curves was less than 8% and average deviation less than 5%, based on the comparison of F–s curves, it can be concluded that the friction coefficient μ = 0.095 describes the contact conditions with adequate precision.

— **Comparison of geometry characteristics**

Verification of the friction coefficient by geometry is done by comparison of three characteristic dimensions: the outer diameter of conical surface D, the inner diameter of flat surface d and the height of specimens h. Due to the impact of alignment between dies and specimens on axial symmetry of specimen after upsetting, the measurement of characteristic dimensions is conducted in four positions, as showed in Figure 7. The average value of four measurings is used to compare experimental results with simulation. For characteristic dimension measurement, optical measuring instrument was used.

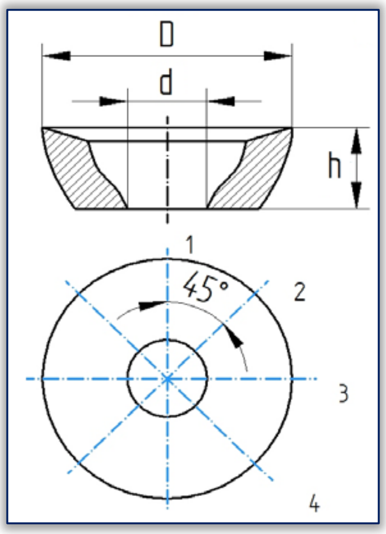

Figure 7. Measuring positions

In Table 1 dimension difference between experiment and simulation results are presented. Subscript *e* represents experimental results, while subscript *s* represents simulation results. For most specimens with 8°30' cone angle, the difference between dimensions from simulation and experiment is less than 0.3 mm, while the maximum difference is –0.74 mm. In the case of specimens with 15°cone angle, for most specimens, the difference is less than 0.2 mm, while the maximum difference is –0.34 mm.

Table 1. Dimension difference between experiment and simulation

Dimension difference:	Specimens with cone angle 8°30'				
	1 – 8	2 – 8	3 – 8	4 – 8	5 – 8
$D_e - D_s$ [mm]	–0.41	–0.25	–0.15	–0.22	–0.74
$d_e - d_s$ [mm]	–0.22	0.00	0.12	0.07	0.37
$H_e - H_s$ [mm]	0.44	0.35	0.2	0.18	0.29
Dimension difference:	Specimens with cone angle 15°				
	1 – 15	2 – 15	3 – 15	4 – 15	5 – 15
$D_e - D_s$ [mm]	–0.06	0.05	–0.13	0.05	–0.18
$d_e - d_s$ [mm]	0.03	0.14	–0.17	–0.09	–0.34
$H_e - H_s$ [mm]	0.07	0.12	0.01	0.02	0.21

4. CONCLUSIONS

Presented results:

— Determined friction coefficient using both types of specimens was $\mu = 0.095$

— Verification of friction coefficient:

The average deviation of the F–s curve was less than 5%, while the maximum deviation was less than 8%

For most of the specimens, the difference between dimensions from simulation and experiment is less than 0.2 mm for a cone angle of 15° and less than 0.3 mm for a cone angle of 8°30'

Since the expected value of friction coefficient for the defined condition was $\mu = 0.08 - 0.15$ and the verification procedure showed good coincidence of experimental and simulation results it is concluded that experimentally determined coefficient successfully describes real process conditions. The determined friction coefficient could be used for simulations and calculations for cold upsetting processes with conical dies and oil lubrication for samples made of steel C45E.

Acknowledgments

This research was presented at the International Conference on Applied Sciences (ICAS) 2019 conference in Hunedoara, Romania held from 9th to 11th May 2019. The support by the Ministry of Education, Science and Technological Development of Serbia under the grant BULKSURFACE–359 is greatly appreciated.

Note: This paper is based on the paper presented at International Conference on Applied Sciences – ICAS 2019, organized by University Politehnica Timisoara – Faculty of Engineering Hunedoara (ROMANIA) and University of Banja Luka, Faculty of Mechanical Engineering Banja Luka (BOSNIA & HERZEGOVINA), in Hunedoara, ROMANIA, 09–11 May, 2019

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