Study of Geometrical Parameters on Friction Calibration Curves of Non Conventional Specimens & Exergy Analysis

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Abstract - This paper aims to investigate the possibilities of alternative non-conventional specimens for friction calibration. From literature survey it is observed that researchers have made attempts to investigate alternate specimens for friction calibration. Research in the last 18 years has led to die-less incremental forming processes that are close to realization in an industrial setup. Whereas many studies have been carried out with the intention of investigating technical abilities and economic consequences, the ecological impact of incremental sheet forming has not been studied so far. It is found that ring compression test is recommended as the standard test for determination of coefficient of friction, because it gives reliable results. There is need to search other friction of friction calibration specimens, which are in same conformity as ring compression test. Two different solid geometry specimens are tried for friction prediction using computer simulation techniques. Finite Element analyses of the compression test are carried out in order to study the deformation behaviour with respect to friction. Based on the deformation studies, correlation has been made between diameter ratios and friction. The deformed radii at various locations for different friction conditions are recorded and it can be observed, that there is continuous decrease in end radius with respect to friction. Friction calibration curves for these specimens are generated. In order to validate the predictability of these specimens, real experiments on them are carried out. Rings of standard dimensional ratio 6:3:1 in the same machine. Friction predictions from both specimen are found to be in close match, proposed alternate specimen offers a powerful tool for friction prediction in the absence of ring specimen. Using the concept of exergy analysis, two ISF technologies, namely single sided and double sided incremental forming, are investigated and compared to conventional forming and hydro forming. A second exergy analysis is carried out with the purpose of examining the environmental impact of different forming technologies from a supply chain perspective. Therefore, related upstream activities (die set production, aluminum sheet production and energy conversion and supply) are included into the exergy analysis.

Key-words: Forming, Friction Calibration Curve, Ring compression; Non-Conventional Specimen, incremental sheet forming, exergy analysis

I. INTRODUCTION

Metal forming processes involve changing the shape of the work piece by forcing it to flow through a die. Forming can be defined as a process in which desired size and shape is obtained through the plastic deformation of a material. Cold forging is defined as working a metal below its recrystallization temperature, but usually around room temperature. If the temperature is above 0.3 times the melting temperature (on an absolute scale) then it qualifies as warm forging. This requires immediate contact between the die (tool) and the work piece. In general, the work piece and the die move relative to each other under pressure or deforming force, which is normal to the die/work piece interface. As a result of this contact, tangential forces are generated at the interface of the die/work piece to resist the relative movement. In order to analyze forming processes, the metal flow, the friction at the die/work piece interface and formability of material have to be described for a given process. For example the coefficient of friction in cold forming is generally of the under of 0.1, whereas that in hot forming can be as high as 0.6.

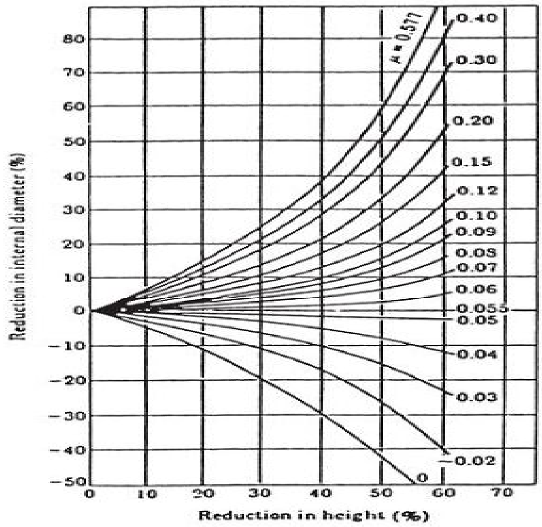


Fig. 1 Friction calibration curve in terms of μ

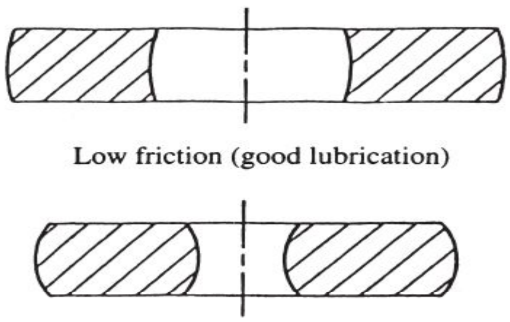


Fig. 2. Deformed ring specimens

II. ROLE OF COMPUTER SIMULATION IN METAL FORMING

In metal forming, a piece of material is plastically deformed between tools to obtain the desired product. Before the digital revolution, only few analytical tools were available to judge the manufacturing feasibility. Today, computer based metal forming simulation tools enable the validation of the tool and machine designs for production and an estimate of the final work-piece properties to be expected. The manner in which the material is worked directly determines the final product quality.

Kaguchi Shin et al. (2000) demonstrated si-tu measurement is method to read data of reduction in height and change in external diameter of ring specimen by testing machine automatically during compressing. Sofuoglu et al. (2001) developed an alternative method to the ring compression test in order to quantitatively evaluate the coefficient of friction, m; at the die/work piece interface. This technique relates the percentage deformation in height of the specimen to the percentage increase in extruded height of the specimen. Sahin et al. (2005) proposed a new approach to investigate the effect of the surface roughness on the frictional properties for different materials and conditions. Three types of steel, commercially pure aluminium and annealed CuZn40Pb2 brass were used as the test materials in the experimental part of the study. Experimental results were placed into ring compression calibration curves for each of the material type and surface conditions. Rudkins et al (1996) performed experimental investigation into friction under hot forming conditions using the ring compression test. Finite-element simulations of the ring compression test were also completed under similar temperatures as in the experiments. The correlation between the experimental measurements and the results of the process modeling is presented in the paper. The analysis had been carried out for different values of friction factor 'm' between the die and the specimen and for different values of initial height to diameter (H/D) ratio of the specimen and curves have been plotted for the ratio of spike height to initial height of the billet against the ratio of die displacement to initial height of the billet. Kakkeri et al (2007) analysized the metal forming processes and found that a realistic frictional condition must be specified at the die/work piece interface in order to obtain accurate metal flow. Sofuoglu et al. (2000) investigated the effects of material properties, strain-rate sensitivity, and barreling on the behavior of friction calibration curves. A series of ring compression tests were conducted in order to determine the magnitude of the friction coefficient, m, as well as the corresponding calibration curves for two types of modeling materials, white and black plasticine. The experiments were first conducted using the Physical Modeling Technique (PMT) and then simulated via an elastic–plastic finite element code (ABAQUS). Robinson et al. (2004) studied the ring compression test using physical modelling experiments and finite element (FE) simulation. Using commercially available modelling clay, material stress–strain relationships were obtained from compression tests of solid cylindrical specimens. A series of ring compression tests were carried out to obtain friction coefficients for a number of lubricants including Vaseline, zinc stearate and talcum powder. FE simulations were used to derive the friction calibration curves and to evaluate material deformation, geometric changes and load–displacement results. Further investigation is necessary to determine the effects of material properties, test conditions and use of calibration curves on the ring compression test. Rao K.P. et al (1993) this paper presents a review of the calibration curves developed by various researchers, and discusses their usefulness and limitations for quantitative evaluation of friction and flow stress. The experimental data obtained for some aluminium alloys is used for comparing the validity of the calibration curves. A calibration using a bulge parameter based on the maximum diameter and minimum diameter of the bulge is then developed as a function of the interface friction factor. Hayhurst et al (2004) proposed a new technique to calibrate the model, which utilizes two test piece geometries, namely the solid cylindrical compression test piece and the ring compression test piece. The geometrical changes of all test pieces, carefully measured throughout the tests, for a range of four different friction conditions, dry friction, lubricant, lead metal and nylon, have been predicted with good accuracy using the true stress–true strain constitutive models, the two-parameter friction model, and the finite-element analysis procedures. Wang. W et al. (1996) developed a new test to incorporating a smooth increase of wrap angle during deformation, even at high deformation rates, thus replicating typical condition die radii. Bugini A. et al (1993) in this study FEM calibration chart for ring upsetting at room temperature is drawn when dealing with annealed Aluminium specimens of different height. The method allows the evaluation of the friction coefficient affecting the plastic flow when Teflon films are interposed between dies and specimens. Lee Chorng-Der et al. (2001) developed a method to find the friction factor of the die/work piece interface for the forging process without the need for measurement of the shape changes of the work piece. B. Buchner et al.(2008) presented an experimental investigation of friction in hot forging of AA6082, which is a standard forging alloy in automotive engineering, mechanical engineering and in naval architecture, by employing a modified ring-on-disc test.. Rao et al. (2008) used cylindrical Al–Cu alloy samples with initial aspect ratios of 1.0 and 1.5 between flat platens in lubricated and dry conditions to predict the metal flow. Micro hardness studies revealed the non-uniform deformation within the specimen. Guerin J.D. et al (1999) in this study The Bay-Wanheim’s generalized friction law, developed to model mixed and thin film lubrication cases, is implemented in an industrial finite element software. Both the axisymmetric and 3D formulations are presented. These developments are validated on the ring compression test and numerical, experimental and analytical results are then compared. Joun M.S. et al (2008) compared and investigated the coulomb friction law and the constant shear friction law in detail using a rigid-plastic finite element with emphasis on their application in bulk metal forming. The ring compression test for two different materials was used to evaluate the two friction laws, and then their effect on metal flow lines and forming loads for various friction sensitive metal forming processes were investigated. It was shown that considerable differences exist between the two friction laws, especially in friction-sensitive metal forming processes.

III. EXERGY ANALYSIS

The method of exergy analysis is well suited for furthering this goal, for it enables the location, type and true magnitude of waste and loss to be determined. Such information can be used to design new systems and to reduce the inefficiency of existing systems. This paper provides a brief survey of both exergy principles and the current literature of exergy analysis with emphasis on areas of application.

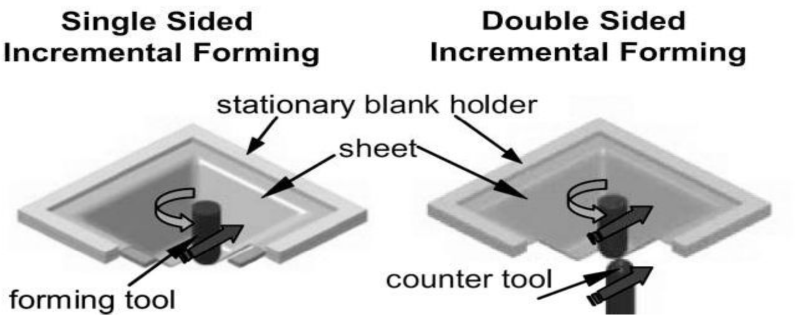


Fig. 3. Incremental sheet forming

III. METAL FORMING FINITE ELEMENT SIMULATION SETUP & EXPERIMENTS

The methodology of this experimental numerical study on investigation of non-conventional friction specimen incorporates following steps:

To obtain the flow curve, tensile test using a commercial aluminum specimen is carried out. An aluminum specimen of gauge length 80 mm, prepared as per ASTM standard, is tested in a Shimadzu make Universal Testing Machine (UTM). The test and tested specimens are shown in . The summary of the results obtained from the tensile test are as follows:

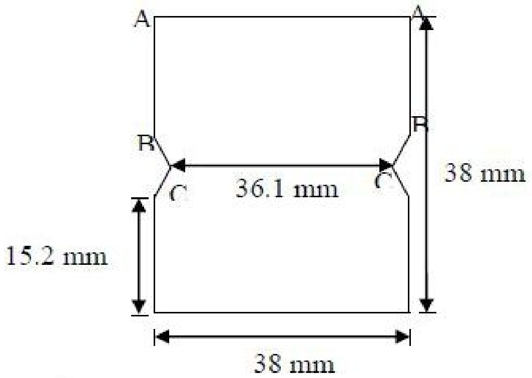
(a) Ultimate Tensile Strength = 161.57 N/mm^2
(b) Yield strength = 123.13 N/mm^2
(c) Ultimate strain = 0.2
(d) Yield strain = 0.002

The engineering stress & strain are converted into their true counterparts using standard relationships (Kalpakjian and Schmid, 2004). Based on these results, material modeling is carried out using the power law equation (Meyers and Chawla, 1997):

$$\sigma = k\varepsilon^n$$

where k is the strength coefficient and n is the hardening exponent. The value of k and n obtained from the tensile test results are 225.4 MPa and 0.095 respectively. These data are used in the finite element (FE) simulations.

Two centre intrude specimens are proposed for friction study. Geometry of the centre intrude specimen I and II are shown in Fig. 3 & 4.



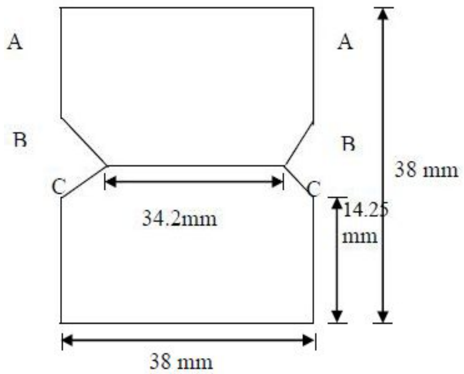


Fig. 4 Geometry of Center Intrude I specimen

Fig. 5 Geometry of Center Intrude II specimen

Fig. 6 Prepared Specimen of Center Intrude I

Fig. 7 Prepared specimen of Center Intrude II

IV. PREPARATION OF RING SPECIMENS

Using the same lathe machine and Aluminum piece two ring specimens are also prepared. The dimensions of the rings are –

(a) Outside Diameter OD = 38 mm
(b) Inside Diameter ID = 19 mm
(c) Height H = 6.33 mm

A typical photograph of ring preparation by Dieter, OD:ID:H ratio is 6:3:1. Thus prepared ring is shown in Fig.8

Fig. 8 Prepared ring specimens

Fig. 9 Deformed specimen centre intrude I

Fig.10 Deformed Ring Specimen

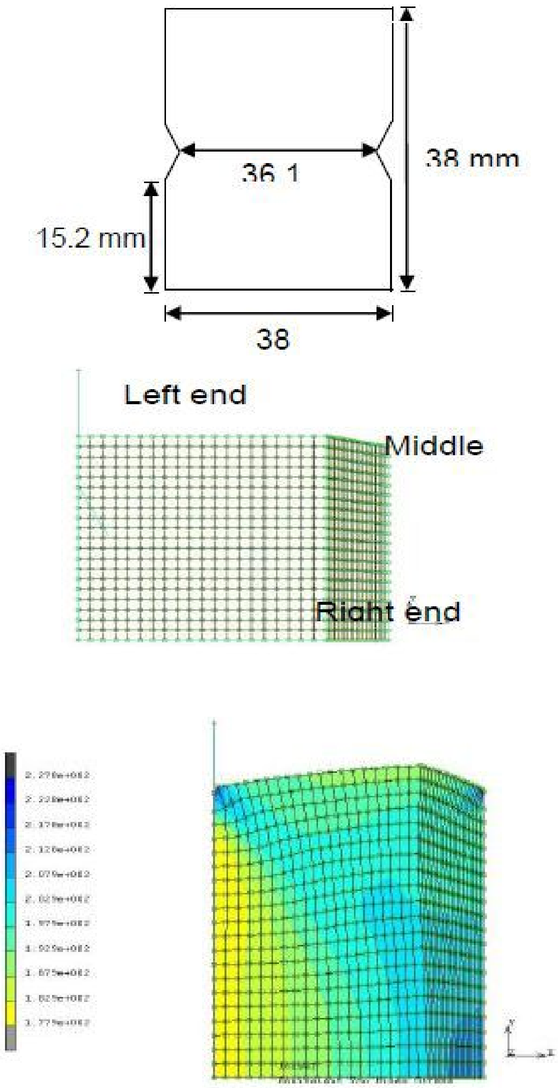


Fig. 11 Geometry, FE & Deformed Mesh of Centre Intrude I

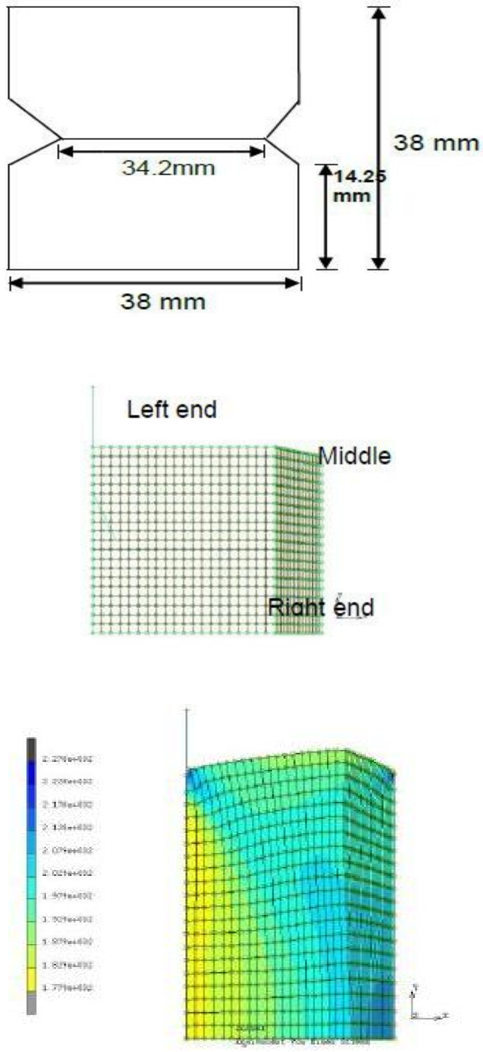


Fig. 12: Geometry, FE & Deformed Mesh of Centre Intrude II

Results of experimental and simulation studies can be described under following heads :-

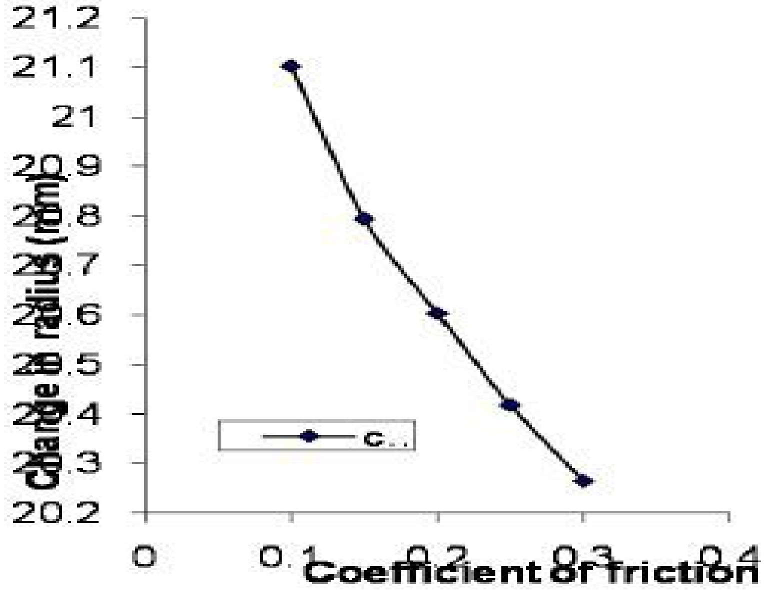


Fig. 13: Friction Calibration Curve Centre Intrude I

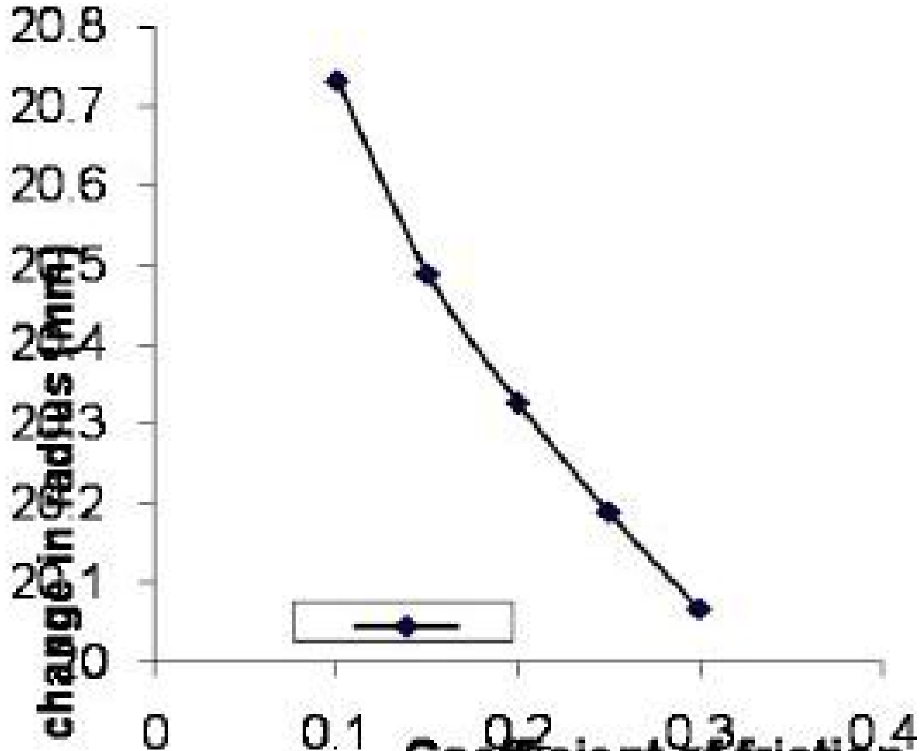


Fig. 14: Friction Calibration Curve Centre Intrude II

Table 1: Specimens and FE Parameters

S.No.	Nomenclature	No. of Elements	No. of Nodes
1.	Center intrude I	800	861
2	Center intrude II	800	861

Table – 2 : Experimental Left End Diameter of Centre intrude I & II

S. No	Specimen Type	Left end diameter		% reduction
		Initial diameter (mm)	Deformed diameter (mm)	
1.	Centre Intrude I	19.0	20.4186	6.94 %
2.	Centre Intrude II	19.0	20.1879	5.88 %

Table – 3 : Determination for centre intrude I & II

S. No.	Specimen Type	Friction (m)	Friction (μ)
1	Centre Intrude I	0.25	0.433
2	Centre Intrude II	0.25	0.433

Table – 4 : Results between Ring Test & Centre Intrude

Case	Ring Test	Centre Intrude	% Error
I	0.45	0.433	3.7 %
II	0.45	0.433	3.7 %

It can be observed that friction calibration curves predict quite accurate results as compared to the ring compression test. Hence such alternate specimens may play important role in friction determination in absence of ring specimens and exergetic analysis of FE simulation.

V. CONCLUSION

In this study a search has been made to find alternative specimens for friction calibration using finite element simulation. Two non-conventional specimens were tried for this purpose. It is observed that these two specimens could undergo consistent deformation with respect to varying friction. Friction calibration curve, for these two eligible specimens are generated using simulation results. Actual experiments on these non-conventional specimens were also carried out. A ring of standard dimension is also tested in the same machine. When compared, both specimen gave very close friction value. These non standard specimens can be used as a substitute to ring compression test for friction determination. Hence, friction prediction becomes quite simple using such specimens, especially in the absence of ring specimens.

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