FRICTION EVALUATION METHOD FOR METAL FORMING BY A COMPRESSION-TWIST TYPE TESTING MACHINE

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Abstract. *This work presents the development of a mechanical systems acting as a new compression twist type friction testing machine in order to simulate frictional conditions prevailing in flat contact for sheet metal forming conditions. Its main objective was to allow for obtaining data for model simulations of the tool-workpiece interface. As a specific objective the operational capacity of the developed system was evaluated trough fundamental friction tests carried out with laser textured surface specimens of an aluminum alloy AA 6016 T4 sliding against an ABNT 1045 steel indenter in order to investigate the friction behavior at an interface (steel – aluminum alloy)*

Keywords.: *Manufacturing, metal forming, friction, twist-compression.*

1. INTRODUCTION

A better control for sheet metal forming is still a great challenge. After reducing the scattering of some effects like mechanical properties, surface defects and lubrication conditions, the surface topography and its effects stands as characteristic with great potential for a process optimization as well as of the formed part. This reinforces the developments needs for new process and test improving sheet metal surface tribological characterization (Batalha 1995,1998, 1999, 2000 and 2001). Concerning the improving of new models used sheet metal forming simulation, some efforts has been made in order to develop new improved test and methods for friction evaluation. In this sense, the conception and construction of new devices and/or equipments for friction evaluation under conditions nearer to the sheet metal forming industry reality represents an important research field, as the both experimental and theoretical modeling approaches, analytical or numerical, need an quantitative evaluation the more accurate as possible for the boundary conditions, specially for a local friction coefficient or factor, acting on the tool-workpiece interface (Schey, 1983, Kawai, 1984, Kalpakjian, 1985 and Budinski, 1992). All tests aiming to evaluate the friction in the toolworkpiece interface need to regard the surface characteristics of this interface, keeping in mind that they change during the forming contact and deformation processes.

Simultaneous relative sliding occurring in this interface causes macro and micro changing on the microstructure and surface topography. This results in a significant variation of the friction coefficient during the forming process (Azushima et al 1998). In most cases, the solution of this tribological problem still not clear due to the great quantity of factors engaged, resulting in errors on the simulation results.

In this work it was developed a plane state twist-compression test machine that allows for friction measurements, aiming simulating condition of flat contact in sheet metal forming. It is discussed some aspects of the structural development of the test machine, its instrumentation and data acquisition in order to measure the interfacial friction. Finally some preliminary results on evaluation of a typical tool-workpiece interface are shown for a SAE1045 punch vs. an aluminum alloy AA 6016-T4 sample.

2. CONCEPTION, DESIGN AND CONSTRUCTION

The development of the structural components tried to follow some previous recommendations about the potential of the plane state twist-compression test for aimed objective (Oyane, 1980, Mizuno, 1982, Kawai, 1987, Fontaine, 1992, Oloffson, 1993 e 1994, Xue et al 1997, Schuler, 1998, Altan, 1999, Kim, 2001, Park, 2001, Ma et al. 2003). Figure 1 shows the test machine after concluded. It was carried out FEM simulations using the software LUSAS in order to evaluate the loading capacity of the structural components. The base support is made of plain carbon steel tube; it contains 8 support radial arms. Over this supports stands a circular table. On this table is mounted a ball bearing, and over this stay a reduction gear train. Figures 2 shows some simulations results for the stress and displacements distributions obtained by using the software LUSAS (Salazar, 2003). Figure 3 shows the loading, stress and displacement distribution for the hydraulic cylinder support plate constructed by welding two C profile beams, with dimensions 40x100x8x270 mm Figure 4 shows the discrimination of loading condition and for the beam acting as column towers of the test machine. The maximum displacement found was 0.08 mm a deleterious value in order to disturb the measurements. Torsion generation system consists of an AC motor with a frequency converter and reduction gear train shown in figure 5. Figure 6 illustrates the developed compression system.

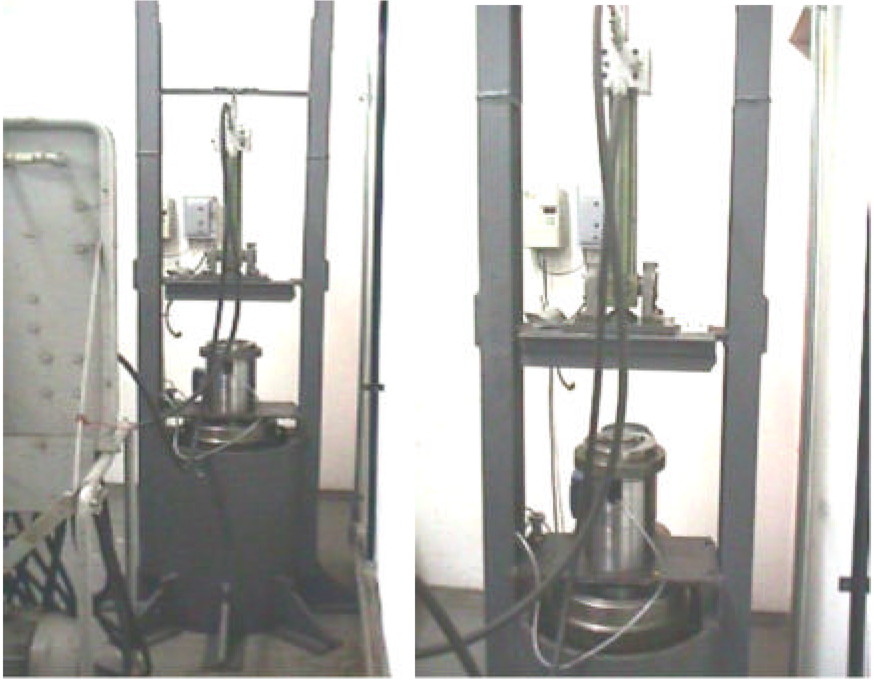
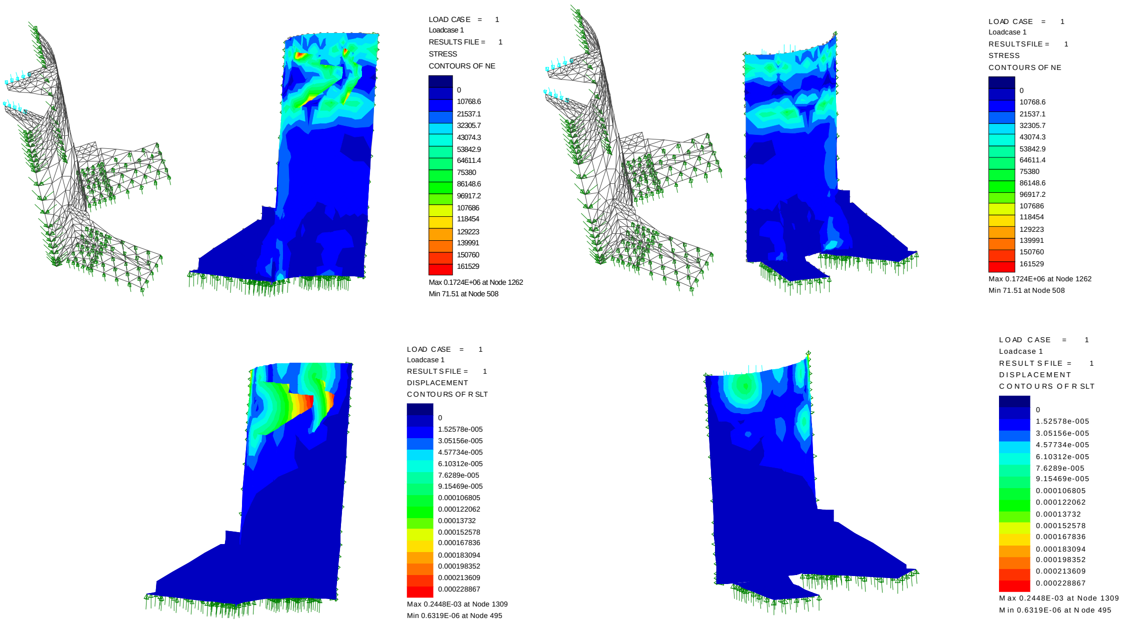


Figure 1 – view of the developed twist-compression machine



(a) internal side (b) external side

Fig. 2 – Loading, stress and displacement distribution: internal and external side of the base.

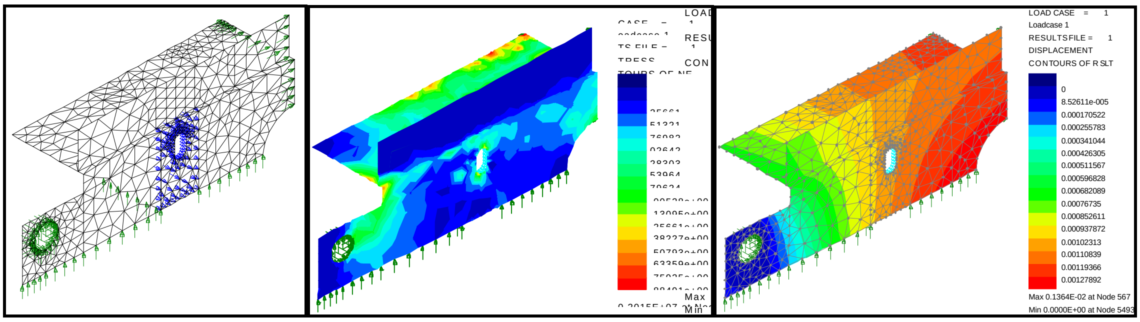


Figure 3 - Loading, stress, and displacement distribution for the hydraulic cylinder support.

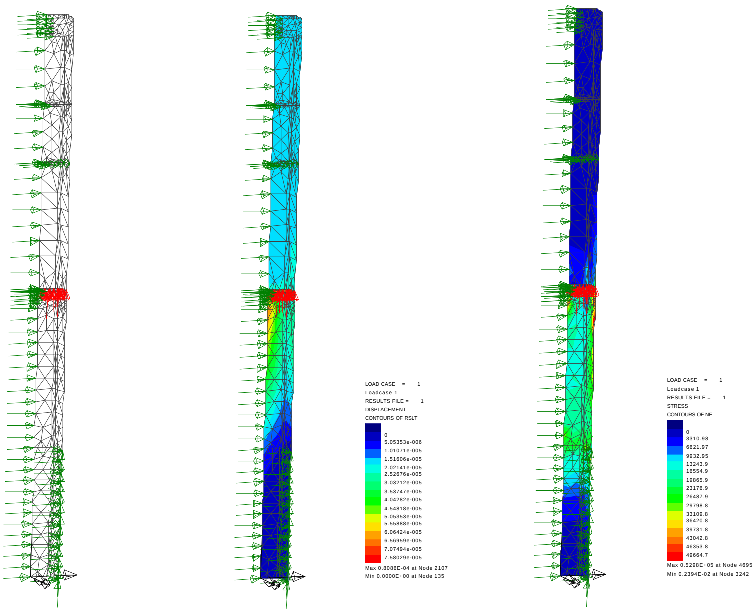
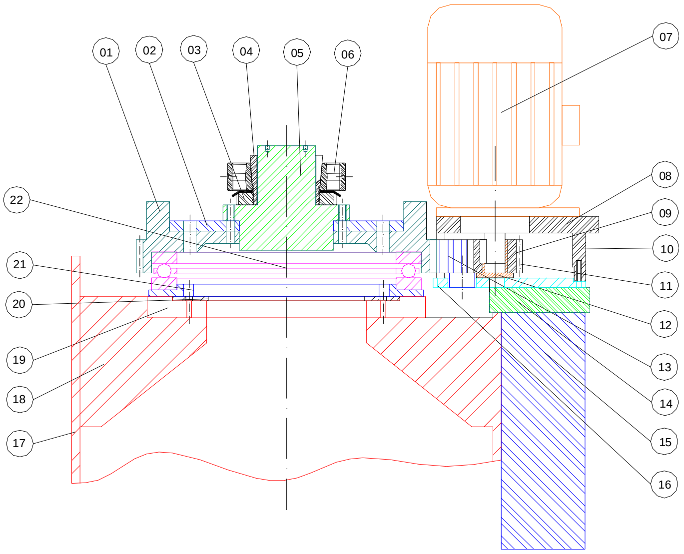


Figure 4 – Loading, displacement and stress distribution for columns beams.



Item	Description
01	gear
02	gear reinforcement
03	Fixing bushing nut
04	Fixing bushing
05	Test piece table
06	Sell compensated roll bearing
07	Three-phase electric motor
08	Supported table covers for the gears
09	Electric motor shaft
10	Support housing for the gears
11	Main gear
12	Fixing bushing for the gear
13	Free gears
14	Supported table for the gears
15	Columns supported table for the gears
16	Lower cover of the gears support
17	Structure base of the test machine
18	Supported table columns of drive system
19	Supported table for the drive system
20	Guides reinforcement of support bearing
21	Support bearing
22	Axial bearings

Figure 5 – Torsion generation system for the twist-compression test machine.

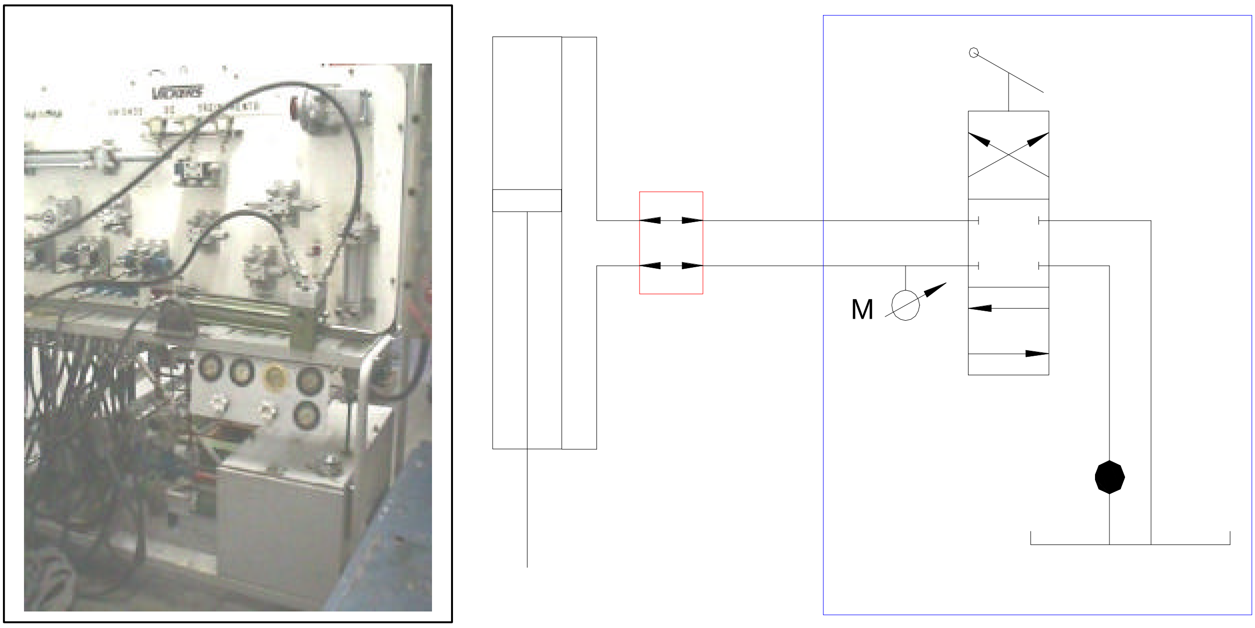
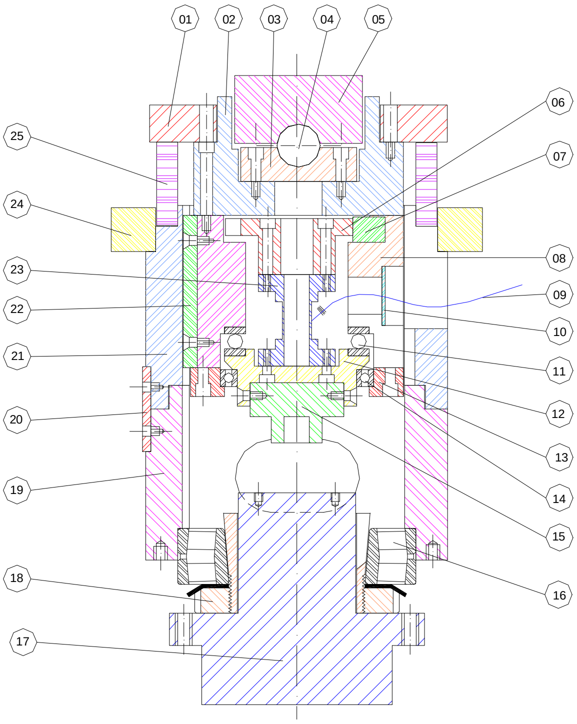


Figure 6 – Compression generation system for the twist-compression machine.

3. FRICTION MEASUREMENT

3.1 The combined twist and compression device

The developed device for the friction measurement by twist and compression is showed in figure 7.



Item	Description
01	spring
02	Housing of lower ball support
03	lower support ball
04	Ball bearings of ϕ 25 mm
05	upper support ball
06	upper fixing of torque cell
07	Taper key of fixing upper of torque cell
08	Central Structure of the measurement device
09	Shielded cable 22 AWG – 4 wire
10	External cover plate for the torque cell cable
11	Axial ball bearing
12	lower fixing of torque cell
13	Cover plate of central structure of device
14	Ball bearing
15	Indenter punch – circular gear
16	Self compensated roll bearing
17	Test piece table
18	Fixing bushing
19	Lower extern carcass of measurement device
20	Assembling guide of device housing
21	Upper extern carcass of measurement device
22	Key for the central structure of measurement device
23	Torque cell
24	Spring support
25	Spring

Figure 7 - Twist and compression device for friction measurement.

3.2 Strain gage sensor development for the torque cell

It was designed and manufactured two torque load cells (Figure 8). They were made of aluminum alloy AA 7475 and contains four strain gages with electric resistance 350 ± 0,4% (Ω) mounted in a full Wheatstone bridge configuration. The torque load cell calibration confirms a linear relationship between the loading and unloading processes until their maximal capacity. This allows for the present configuration to operate with torques ranging from 0 to 20 N.m.

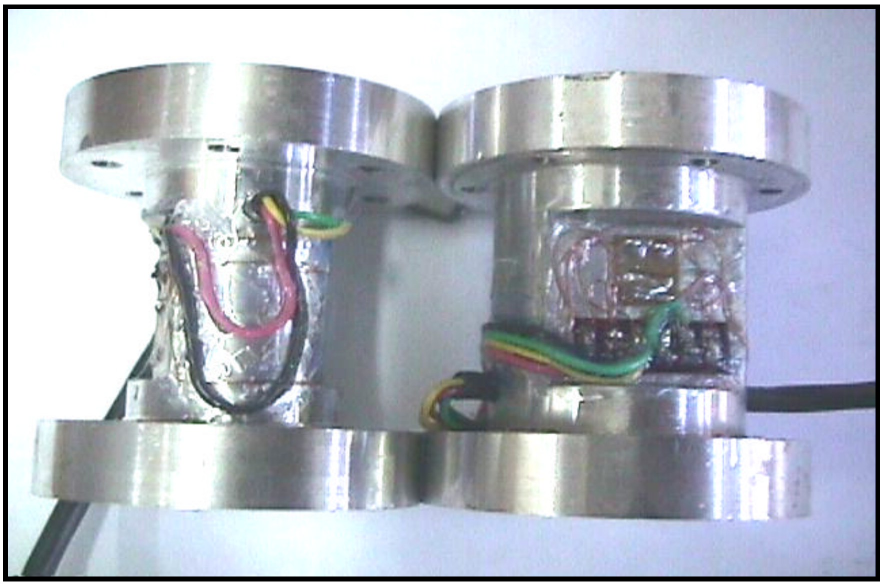


Figure 8 – strain gage based sensor for the torque load cell.

4. Experimental Development

During the experimental developments it was carried out measurements in order to evaluate de friction coefficient for the tool – workpiece interface 1045 steel against AA-6016 sheet metal test piece under dry conditions.

4.1. Test pieces

The tested work pieces were sheet metal samples form AA 6016-T4 (Al-Mg: 0,4; Si: 1,2) aluminum alloy, with thickness of 1,2 mm and surface texture as shown in Figure 3. Their surfaces texture is deterministic roughness textured pattern generated with laser textured rolls. The mechanical properties as well some roughness parameters are listed in the table 1.

Table 1 – Mechanical properties and roughness characterization

Mechanical Properties:	
Ultimate Tensile strength : 211,2 MPa	Planar anisotropy coefficient : 0,21
Lankford anisotropy coefficient : 0,68	Strain rate exponent : 0,23
Unloaded surface roughness parameters (DIN 4768):	
R_a , longitudinal (µm) : 1,10	R_z , transversal (µm) : 4,49
R_a , transversal (µm) : 0,79	R_{max} , longitudinal (µm) : 7,32
R_z , longitudinal (µm) : 4,37	R_{max} , transversal (µm) : 6,06

4.2. Indenter Punch (see Figure 10)

- Material: carbon steel SAE 1045
- Yield strength: 300 MPa
- Ultimate tensile strength: 525 MPa
- Average roughness on the contact face: Ra radial = 0.8 µm]

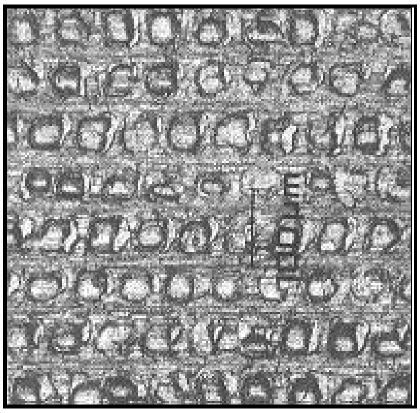


Fig. 9: workpiece surface topography aspect

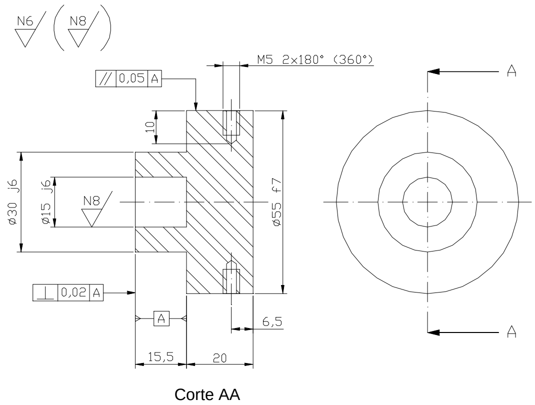


Figure 10: Indenter punch

4.3. FEM modeling for the plane state twist and compression

The FEM modeling for the plane state twist and compression testing was applied in order to verify and predict stress concentration as well as possible non uniform strain distributions at the test piece interface pressed and twisted by the indenter punch. The analysis was made using the software ALGOR, more details about the adopted procedure is given in Valdez Salazar 2003. Some input parameters used for the simulation are listed in table 2.

Table 2 – Simulation parameters for the twist and compression model by ALGOR software

E steel : 210 GPa	Punch contact area : 530 mm^2
E aluminum : 69 GPa	Punch external diameter : 30 mm
Poisson coefficient : 0,33	Punch internal diameter : 15 mm
F_{normal} : 100 a 200N	$F_{friction}$: 10N a 90N

The simulations regard typical loading conditions for the punch. Figure 12 shows a FEM simulation for a normal force (Fn) of 220 N. It can be observed in this case a sharply region submitted directly to the normal forces and moment. In the marginal regions the contact area with the punch, the stress distribution is uniform as well as showing out from the punch contact exhibit low normal forces and moment not affecting the friction measurements.

4.4. Surface aspect of the test pieces after the plane state twist – compression test

After carrying out the tests it was carried out a surface evaluation of the test pieces after the twist and compression tests. Figure 6 shows a sample test pieces of aluminum alloy AA 6016 T4 tested at 190,3 N under no lubrication (dry condition)

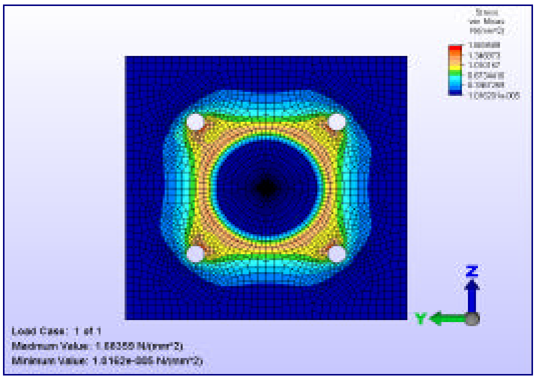


Fig. 11: Von Mises stress distribution at contact

Fig. 12: Surface after the twisted-compressed

4.5. Data acquisition system

By a previous study of the noise – signal ration, common in the development of a data acquisition system, it was verified the need of a filtering and amplifying the electrical signal coming from the sensor in order to avoid an information loosing during the data transfer. The filtering process was made by analogical and digital processing. The analogical filtering was carried out with a lower band variable frequency one, while the digital filtering was carried out using the software Mat Lab.

4.6. Experimental results for the friction evaluation

After the graphical recording of the measurement results obtained for the twist-compression test it was carried out a comparison with the published results of Kawai 1987. Observing the results of in figure 13 it can be identified three stages. The first one corresponds to the previous moment before the twist-compression loading representing noise. The second stage shows the sensor output during the loading and finally the third stage shows the sensor output after removed the loading, i.e. again a signal similar to that from the first stage.

The raw signal output from the sensor, after a suitable filtering and amplification (discussed in 4.5) results in the acquired measurement signal showed in figure 14. It represents the Coulomb friction coefficient evaluation against the displacement. It can be noted the from 0,5 to 7,5 mm the relative displacement occurs an increasing for the Coulomb friction coefficient until circa 0,45 (static friction) falling during the following 3,5 mm to values in range of 0,22 to 0,3 (steady state regime).

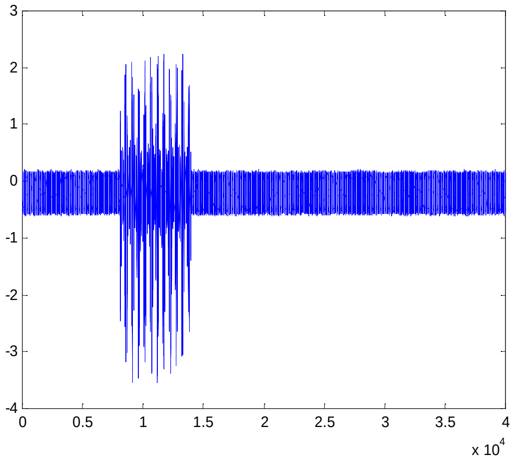


Figure 13: number of points vs. tension changing, Normal load: 190,30 N.

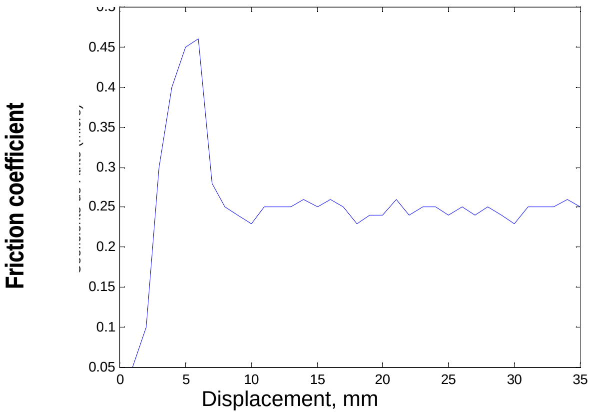


Figure 14 : Friction coefficient vs. Displacement Fn = 190,3 N

Table 1 lists average values for measured friction coefficient and a resumed table for the values of the friction, T_{max} e T_{min} for different loadings levels attained during the twist-compression tests of an interface of a steel SAE 1045 indenter punch and sheet metal test piece AA 6016-T4 tested under dry conditions.

Table 1 : Experimental measurements outputs for the friction coefficient values

Loading (N)	μ	F friction (N)	T min (N.m)	Tmax (N.m)
110,0	0,253895	27,92848	0,41893	0,83785
126,4	0,273252	28,95476	0,43432	0,86864
142,5	0,253078	36,06357	0,54095	1,08191
158,5	0,251074	39,79530	0,59693	1,19386
174,5	0,248963	44,34873	0,66523	1,33046
190,4	0,248355	47,26201	0,70893	1,41786
μ average = 0,254770			T average = 1,0634 N.m	

After concluding these tests the correspondents measured friction coefficient values closes to theoretical values of the literature and stays less than the critical value $\mu_{max} = 0.577$

5. Conclusions

It was developed a mechanical system acting as forming press working in plane twist – compression conditions, which allows for the friction investigation under flat contact in metal sheet forming.

The following conclusions can be drawn about the its functional and operational capacity, regarding a sheet metal AA 60116 T4 aluminum sheets twisted and compressed against a steel SAE 1045 indenter:

- The tests allowed for a verifying the accuracy of the developed testing system in order evaluate friction conditions.
- The experimental results follow the theoretical waited frictional behavior, exhibiting a static maximum value followed by a steady state regime value for the dynamic friction coefficient.
- The plane state twist and compression results predicted theoretically were confirmed after the experimental evaluation of the deformed track in the sliding path verified in the loaded test pieces.

6. Acknowledgements

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7. References

Altan, T., Oh, S. & Gegel, H., 1999. Conformação de metais – Fundamentos e Aplicações, 1ª ed., Publicações EESC, São Carlos, pp. 85-91 e 103-132.

Azushima, A. & Kudo, H. ,1998, Effect of surface topography of workpiece on pressure dependence of friction.

Batalha, G. F., 1995, Influência da camada anodizada sobre o atrito na conformação plástica do alumínio, Tese (Doutoramento), EPUSP, S. Paulo.

Batalha, G. F., 1998, Some aspects of Surface Qualification and its relationship to metal sheet forming, In: Proc.. I Workshop FINEP/RECOPE – Desafios, Experiências e Expectativas no controle da rugosidade de chapas metálicas para a indústria automotiva, october 21, 1998, Org. EPUSP / FINEP / RECOPE, S. Paulo, ISBN 85-86686-03-4.

Batalha, G. F. et al. 1999, Proc. II Workshop FINEP -RECOPE – Qualificação de chapas para a indústria automobilística, 17 de abril de 1999, Org. EPUSP / FINEP / RECOPE, S. Paulo, ISBN 85-86686-05-0

Batalha, G. F. & Stipkovic Filho, M., 2000, Analysis of the contact coditions and its influence on the interface friction in forming processes, In: Metalforming 2000, Pietrzyk et al., Balkema, Rotterdam, ISBN 90 5809 157 0, pp. 71-7.

Batalha, G. F. & Stipkovic Filho, M., 2001, Quantitative Characterization of the surface topography of cold rolled sheets – new approaches and possibilities, J. Materials Processing Technology, 113, pp. 732-8.

Budinski, K. C., 1992, Laboratory testing methods for solid friction, In: ASM Metals Handbook, friction, Lubrication and Wear Technology, Vol.19, 9 ed., pp. 27-58

Canova, G. R. et al, 1982, The use of torsion testing to assess material formability, In: Formability of Metallic Materials, ASTM STP 753, ASTM, pp. 189-210.

Doeblin, E. O., 1990, Measurements Systems -Application and Design, 4ed., McGraw-Hill.

Fontaine, J. F. 1992, The Torsion-Tensile Testing for the characterization of cold metal formability, Journal of Materials Processing Technology, Vol. 32, 253-262.

Kalpakjian, S.,1985, Recent Progress in Metal Forming Tribology, Annals CIRP, 585-92

Kawai, N. & Dohda, K., 1984, Tribology in Metal forming Processes, Advanced Technology Plasticity, Proc.International Conference on Technology of Plasticity, Tokio, pp. 145-56.

Kawai, N. & Dohda, K., 1987, A new lubricity evaluation method for metal forming by a compression-twist type friction testing machine, Transactions ASME - Journal of Tribology, v.109, pp. 343-50.

Kim, Y. H., Park, J. H. & Jin, Y. E., 2001, An analysis of plastic deformation processes for twist assisted upset forging of cylindrical billets, Journal of Engineering Manufacture, Part B, Proceedings of the Institution of Mechanical Engineers, 215(6), 883-6.

Ma, X., Barnett, M. R. & Kim, Y. H., 2003, Experimental and theoretical investigation of compression of a cylinder using a rotating platen, International Journal of Mechanical Science, 45, pp. 1717-37.

Mizuno, T. & Hasagawa, K., 1982, Effects of Die Surface Roughness on Lubricating Conditions in the sheet Metal Compression - Friction Test, Transactions ASME - Journal of Lubrication Technology, v. 104, pp. 23-8.

Ollofson, U., 1993, Friction Characteristics of a ferritic-austenitic stainless steel during lubricated reciprocating motion, Wear, 170, 235-45.

Ollofson, U. & Holmgren, M., 1994, Friction Measurement at low sliding speed using a servo hydraulic tension-torsion machine, September 1994, pp. 202-7.

Oyane, M.; Shima, S. & Nakayama, 1980, T., Universal Testing for Workpiece Material, Tool Material and Lubricant in Metal Forming, The Int. Symposium on Metal Working Lubrication, San Francisco, pp. 13-21.

Park, J. H. Kim, Y. H. & Jin, Y. E., 2001, Experimental investigation of the forming parameters of the rotational upset forging process, Journal of Material Processing Technology, 1-3, 103-6.

Schey, J. A., 1983, Tribology in metalworking, ASM, Metal Park - USA.

Schuler, 1998, Metal forming handbook, Springer Verlag, pp 25-31, 310-13

Valdez-Salazar, C. E., 2003, Desenvolvimento de uma máquina de compressão-torção para medição do atrito em processos de conformação de chapas metálicas, Dissertação de mestrado, Escola Politécnica da Universidade de São Paulo, São Paulo.

Xue, K., Wang, Z., Lu, Y. – FEM analysis of cylinder twist-compression deformation regularity, Journal of Material Processing Technology, 1997, 69, 148-51.

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