

Towards a Hybrid Twin Model to Obtain the Formability of a Car Body Part in Real Time

Ivan Peinado-Asensi^{1,2,a}, N. Montes^{1,b}, E. Garcia^{2,c} and A. Falcó^{1,d}

¹CEU Cardenal Herrera University, Alfara del Patriarca, Spain.

²Ford Motor Company, Almussafes, Spain.

^aivpeias@gmail.com; ^bnicolas.montes@uchceu.es; ^cegarci75@ford.com; ^dafalco@uchceu.es

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Abstract. In recent days there are many possibilities in develop solutions for industrial manufacturing process thanks to the emerging technology based in Industry 4.0, where one can measure and manage data from an industrial process in real time been able to know more information than ever before from the process. But still having challenges in complex process where monitoring data and give a solution is less intuitive, mostly due to a complex physical definition of the process and manufacturing car body parts in automotive is a clear example. In deep drawing process is common to have variations in the process parameters and they can carry out bad manufactured parts. The cycle time, the robust process and the complex physics in the process are the main problems to obtain feasible information from the process. In the following it is proposed a new methodology to have full knowledge of the process applying the so-called method Hybrid Twin.

Introduction

The manufacturing process of the chassis parts of a vehicle consists of several stages. This begins with the design of the different parts, from the prototyping, the realization of the CAD, and the verification that the geometry of each one fits obtaining a validated final product. Next, simulation software was used where physical parameters are obtained that verify whether it is possible to manufacture these parts meeting different requirements, both structural and design. Once validated, on the one hand the matrix is sent to manufacture to form the sheet and on the other hand the stamping lines are configured according to the optimal parameters obtained from the simulation to start with mass manufacturing. What usually happens in this process is that the results obtained in the simulation with respect to those of reality differ, which supposes the great battle of the manufacturing engineers, to achieve the desired quality, from the parameters obtained in the process of simulation. One of the techniques commonly used in the industry to adjust parameters online is to obtain an FLD (Forming Limit Diagram) of the actual part produced that has previously been meshed. Once the part is manufactured, the mesh is captured by a vision system, allowing us to know which part has had more critical deformation to more effectively readjust the parameters obtained from the simulation.

The battle to ensure the quality of the product manufactured in the stamping process that manufacturing engineers deal with, is not only based on readjusting the parameters obtained in simulation, but also, during the manufacture of parts, these can present defects in a random way despite having correct job parameters assumptions. In this case, the physical models used to calculate the behaviour of the sheet depending on the situation in which they can be closer or closer to the real result. The greatest difficulty is that the working parameters vary as production progresses since the manufacturing process is very volatile and there are frequent variations, either due to wear of the die, changes in the parameters of the working state of the press or problems in the material used, directly affecting the quality of the final piece, either due to the appearance of cracks, wrinkles or seizures, among others. Automotive companies invest large resources in quality control of the part since if a defective part goes to subsequent manufacturing processes the cost when said defect is located is very high, since it appears when the part is already assembled in the bodywork end and must be scrapped.

To improve the stamping process, it is necessary to improve the simulation. Research is mainly focused on improving modelling that allows for fine-tuning of the output. It has been proven in

numerous investigations that one of the most critical parameters is friction [8]. In the literature, different procedures can be found to validate models applying different estimates of the coefficient of friction. In general, the Coulomb coefficient of friction [9] is applied, but models dependent on the pressure and speed of the equipment can also be found [5], in addition to tribology simulations adjusting the friction depending on the materials and lubricant used [10]. There are even proposals that propose approaches for sheet metal forming, neglecting contact, ignoring the friction [11].

In general, these investigations are developed following the same process, they generate experiments and manufacture of simple parts in vitro and on many occasions the result obtained does not agree with that obtained in the manufacturing line. This is because they are simplifications of the process, obtaining an approximate result of what may happen, as can be seen in [3].

This article proposes the development of a Hybrid Twin model in order to enrich a friction model dependent on the pressure and the speed of the press, using real output data from the stamping process, which will allow the inclusion of the physics of the real system not considered in in vitro experiments [2]. In this paper we have chosen to apply the P-V dependent friction model developed in [3] due to the good results obtained in vitro. In addition and following the philosophy that was raised from the beginning in this research, we have the necessary parameters at our disposal already installed in the series press, [1] maximizing the savings in installing new equipment.

The distribution of the paper is as follows; in the next point we will talk about the starting hypothesis taken according to the above. In point 3 the initial approach to be developed of the digital twin will be defined, in point 4 the tool to be developed will be defined and finally in point 5 we will show the conclusions and future work.

Stamping Process

In the Stamping Plant facilities at Ford Spain, you can find mostly mechanical but also hydraulic presses. The research is being carried out in a Single-action (SA) press with a cushion system. The difference between SA and Double-action (DA) presses is the eccentric drive transmission system and the Blank Holder Force (BHF) system. In SA presses there is one slide for the tool and a cushion system as blank holder that make the Deep Drawing operation more effective, and one can reach faster cycle time per produced part. As explained in [12] during the thesis, an application has been developed that allows us to monitor the work parameters in real time by taking data from the PLC that governs the press. Variables such as Tonnage load, Counterbalance Pressure, Overload Pressure, among others are being monitored. The data is recorded in a database for later analysis and visualization if required. Being able to view the working parameters of the press from any device of the company in real time.

From these variables, the speed and tonnage data will be used to develop the proposal of this article. Figure 2 shows a comparison of the evolution of tonnage VS speed for a stamping cycle. We define the position of the press to know where we are in the cycle depending on the rotation of the main axis of the eccentric system, it makes a full turn each stamping cycle so the cycle is divided into 360 positions, depending on the degree of rotation where it is. Thus in the graphs we can see the heat of each variable from the press position 0

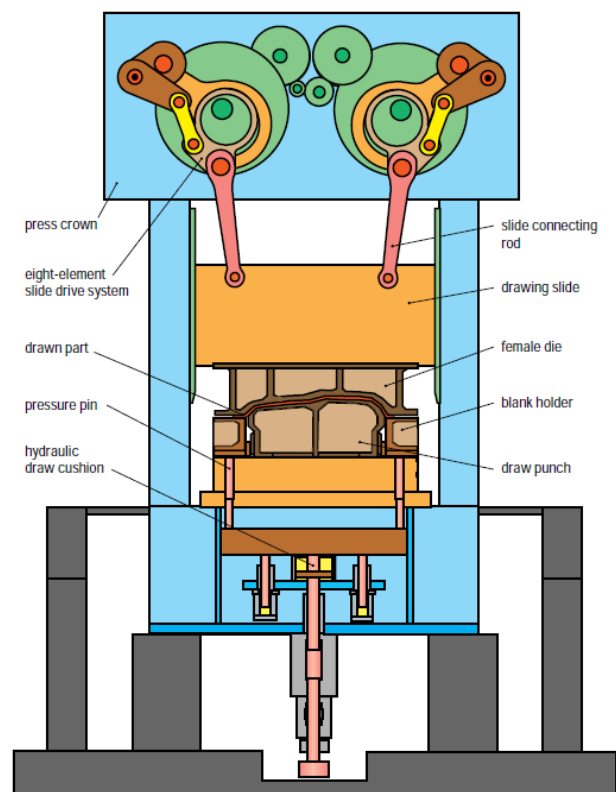


Fig. 1: Single Actions Mechanical Press

to 360. The 180 degree would be the lower dead center of the press, when the piece has already been formed.

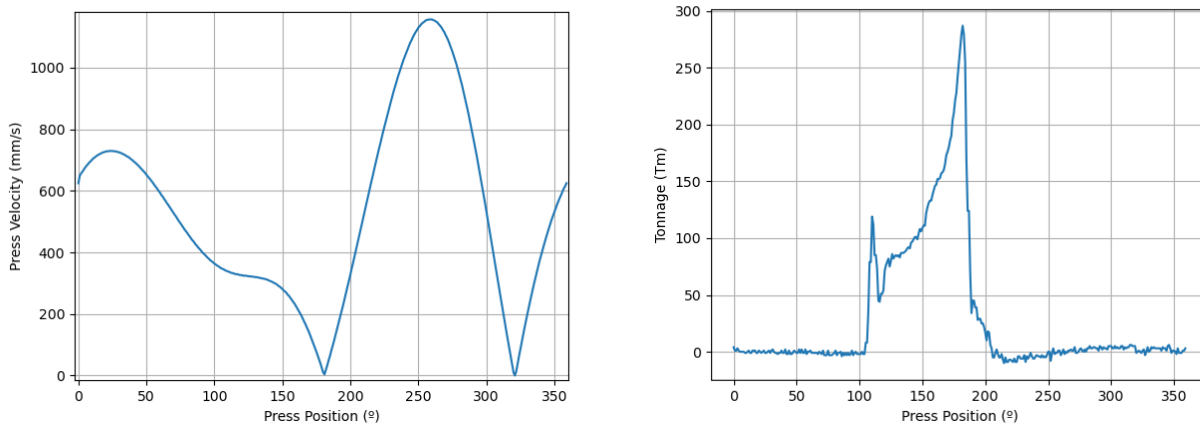


Fig. 2: Press Velocity (left) and Tonnage Load (right) of a stamping cycle.

Starting Hypothesis

The importance of obtaining a correct friction coefficient that allows adjusting the simulation and reality results can be seen in different use cases as in [4]. In this work, after a simulation using the Coulomb friction model, the simulation gave them correct but the part made with the real process was defective. To solve this mismatch, they applied tribology simulation techniques to obtain an effective friction coefficient that could identify the defective area in the simulation to later make the pertinent adjustments in the matrix and avoid breakage. It has also been verified how by developing pressure and velocity-dependent friction models, the so-called P-V friction dependent models, it was possible to obtain different thicknesses in the simulation. In other investigations, models are presented to obtain a greater or lesser value of the stress of the press depending on the coefficient of friction [6], where it is obtained that the greater the friction, the resultant of the stress made by the press is greater and less thickness of the final piece. Recently in [3] they propose the application of a variable friction coefficient during the stamping process, proposing the following P-V friction dependent models.

$$\mu = \frac{1.849P + 13.3}{(P + 2.446)(0.9193P + 1.467 + v)} \quad (1)$$

Where we will name the coefficients such that, $a = 1,849$, $b = 13.3$, $c = 2.446$, $d = 0,9193$ y $e = 1.467$. Based on a tribology experiment on a 5052 Aluminium Alloy with a fit of up to 97.7% from the μ obtained from the tribology test. Although the result obtained in [3] is not directly applicable to our process since the materials differ, they are similar enough to be able to carry out a test that allows us to see if the form of the function $\mu(P, v)$ it may be suitable to be used in our actual process.

Function form test $\mu(P, v)$. Applying in the model proposed in [3] the speed and tonnage data obtained from our process in real time for a random piece of steel, the result obtained is the figure 3. Where the x-axis is the position in degrees of the matrix. The stamping process is carried out between position 150 and 180 where the press is located in the Bottom Dead Center and the piece is fully formed.

The expected frictions in our case, steel-steel, would be between 0.09 and 0.15. In the case of [3], where they used steel-aluminium, the expected values obtained are between 0.2 and 0.6 under certain specific conditions, see [7]. As we can see in figure 3, the friction values fall within the theoretical margins. The increase in friction as the press descends corresponds to an increase in the load, which is consistent with the experiments carried out in [3].

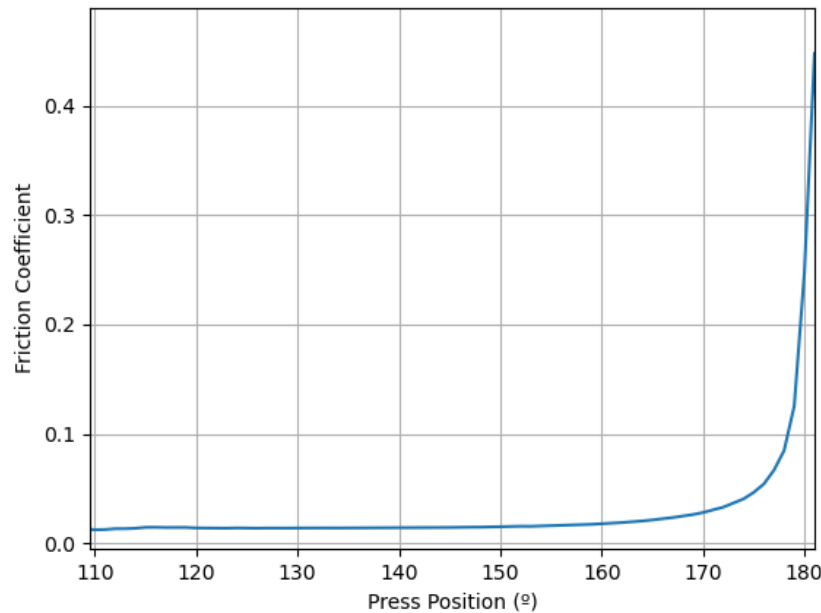


Fig. 3: Variable friction coefficient

Therefore, it is proposed to obtain the coefficients of the P-V friction dependent model by applying the Least-Square Method with a known friction coefficient of our process under our working parameters.

The challenge here is to know the real μ real of our process, a variable that is difficult to measure and that we do not have monitored. An approximation of the variable could be obtained by means of tribology with samples of the materials used, but the development of a tribological test with the different materials does not fall within the scope of this research, because as we have commented on this type of tests carried out with laboratory tests they usually differ when applied to the actual process. As the purpose of this research is to obtain new variables of the process without making extra investment in sensorization equipment, it is proposed to obtain μ by applying the concept of the hybrid twin. In the next section we will describe the process to follow to obtain the friction coefficient in real time by using simulation and the available parameters.

Hybrid Twin Enrichment Model

Available Data. In the plant, numerous quality processes are carried out to ensure that the different manufacturing processes comply with the standards that stipulate that the final product will not have defects, between the different control measurements of the thickness of each one of the different pieces are carried out. that belong to the vehicle. These measurements are routine tests that are made every certain number of manufactured parts to verify that if a side, a door, or a ceiling, for example, are within the required quality standards, the manufacturing process has not produced defective parts.

Of the simulations of the parts that are manufactured in stamping, of the different results that can be obtained the most used are the Forming Limit Diagram (FLD) which tells us the deformations in each area of the defining mesh along the surface of a piece and the percentage of stretch of this. These are two results that we can obtain from a real part produced by using techniques other than simulation.

Enrichment proposal. What is proposed is, from the final result of the piece, either the real FLD or thickness measurements made in the quality inspection and together with all the available parameters of the real process, such as material properties, lubrication, geometry and working parameters, carry out the reverse path of the simulation and obtain the friction coefficient produced by that thickness. The following figure shows the schematic of the process.

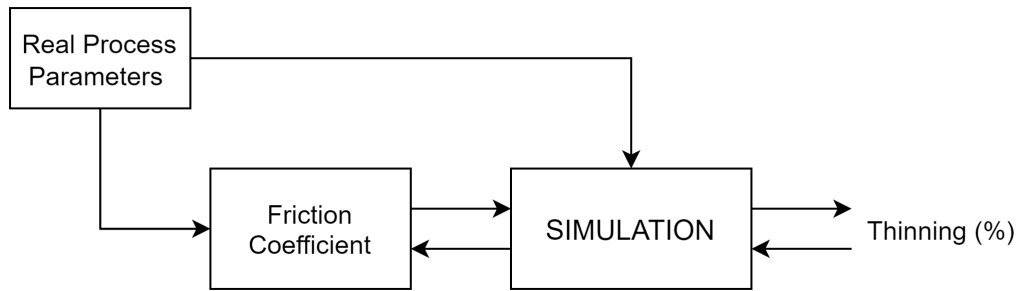


Fig. 4: Hybrid-Twin Model Diagram

Stamped Product Information (FLD). As it was just mentioned, we can have the strain (ϵ) of a stamped plate, where we can get the information of every node all over the surface. The process starts printing a mesh in the plate by electrolytic marked. Afterwards, the part is stamped is took to the laboratory and with a high-resolution camera, with 20 million of pixel, photos are taken of the different areas to be analyzed, the example shown in figure 5 is the central beam of the measured part. Using the AutoGrid® software it is obtained as output the FLD of the area analyzed with the strain of every node measured, showing the maximum strain ϵ_1 and ϵ_2 per node in the diagram with the bounds of the diagram previously defined for the specific material.

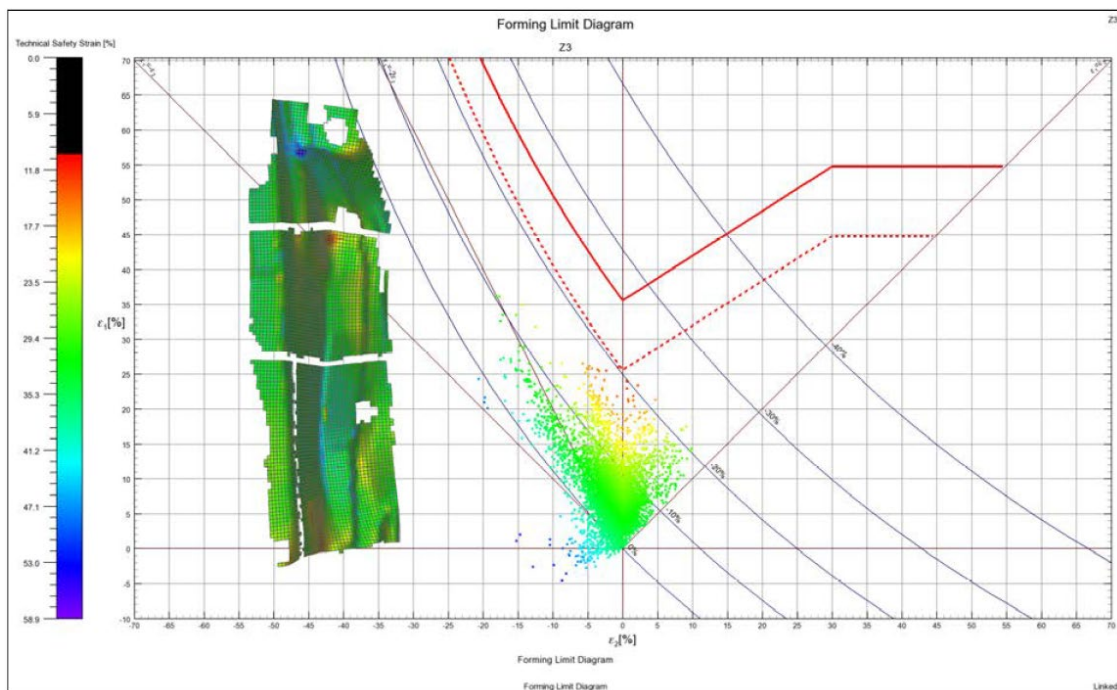


Fig. 5: Forming Limit Diagram of a Real Stamped Part

It is possible to obtain the information of the FLD test as data set, so it makes easy to used afterwards to our purpose to design an accurate methodology to detect the probability of failure in real time.

Thickness Measurements. With the strain known we can assure that we have the output of the simulation to make and appropriate inversed simulation, but as we are looking to obtain the appropriate friction coefficient it is also going to be measured the thickness of the areas where the radius is more pronounced. The data has been measured with a mechanical thickness gauge such the one that can be seen in figure 6. The exact region measured in the Ford Kuga side panel is shown in figure 7, with previously measured sheet thickness of 0.73 mm . The different measurements that were taken of the piece after stamping can be seen in table 1, with a thickness reduction of about 20% in some points. Considering that the manufactured part was took as good, we can say that this percentage of reduction for the thickness of the sheet used would be adequate. The exact measurement point is in the area closest to the radius, and this



Fig. 6: Thickness measurement

performs an angle of approximately 90 degrees ($^{\circ}$) and cracks or wrinkles usually appear depending on the configuration of the process variables. In Table 1 you can see the results obtained from the measurements that will later be compared with the results obtained in the simulation applying the actual measured work parameters.

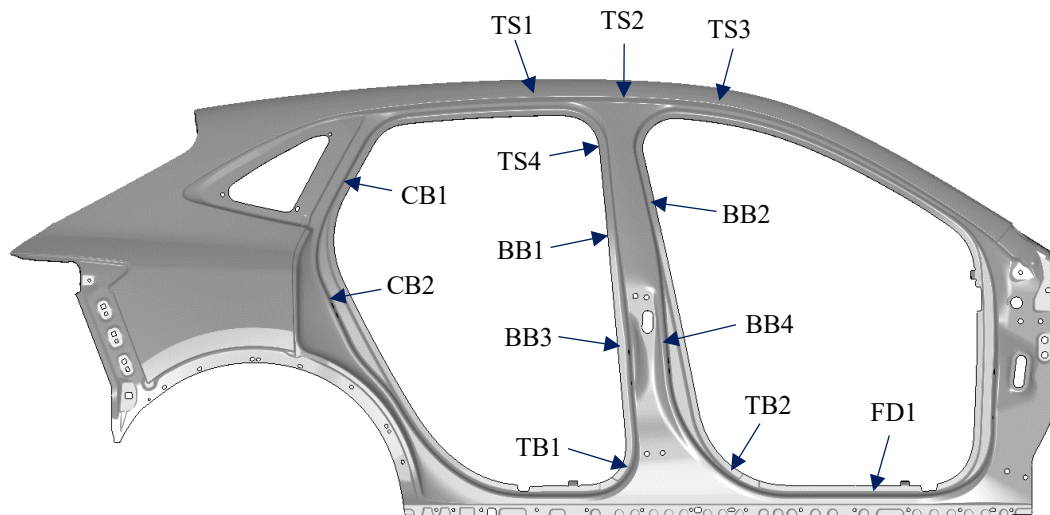


Fig. 7: Body side thickness measurement

Table 1: Thickness measurement

Point	Thickness [mm]	Thinning [%]
TS1	0.59	19.1780822
TS2	0.67	8.21917808
TS3	0.66	9.5890411
TS4	0.67	8.21917808
BB1	0.68	6.84931507
BB2	0.62	15.0684932
BB3	0.63	13.6986301
BB4	0.64	12.3287671
CB1	0.69	5.479452055
CB2	0.67	8.21917808
TB1	0.68	6.84931507
TB2	0.62	15.0684932
FD1	0.64	12.3287671

Inverse Simulation. As shown in the paper, huge amount of information from the process can be obtained, both input and output. Material properties, process parameters and final product status. Now, the intention is to use simulation software and verify the following, for a manufactured part in the process, their outputs match with the physical outputs measured directly from the part, seeking to make it as tight as possible, all this introducing our measured working parameters. When the result is verified as expected, we will proceed to calculate the PGD of the process to identify the state of every part in real time. But as we have said, the process is volatile and the working parameters may vary, especially those of the press, such as the blank holder force, wear of the die, etc., there may even be a change in the material properties. Therefore, an adjustment of the parameters of the PGD obtained would be carried out, fed with the new parameters to find the desired result while minimizing the error.

Friction Coefficient Adjustment. As exposed, μ is a critical parameter when it comes to obtaining one result or another in the simulation, and the result can vary drastically in certain areas. Being a key parameter to obtain the thickness of a piece, furthermore the friction coefficient can be modified throughout manufacturing period due to wear of the matrix or modification of the lubricant used. In the Hybrid Twin Method proposed, we are going to calculate the variable friction coefficient throughout each cycle with press speed and tonnage data monitored from the process, and it will be applied it to the simulation using PGD to verify the result of the manufactured part.

Conclusion and Future Work

Here we present the first steps taken to develop the Hybrid Twin Model in the stamping process in the Ford Spain presses with the purpose to identify the probability of a crack appear, either in the stamping process itself or in the following processes manufacturing, such as the seaming and assembly of the chassis or in the ovens after the painting process. To obtain the result of every one of the pieces produced, techniques that are not restricted by the cycle time are required, as is the case of the PGD, where performing previously offline simulation calculation, allows us during the process identify the defect in the part. The large amount of information on the process that we have at our disposal for both, the part and the equipment has been presented. By designing an organized process of the above, it is intended to achieve the mentioned hybrid model. At this point, the investigation will continue to carry out the following. Through inverse simulation, with the known outputs, obtain the working conditions that would give this result, which, compared with the measurements taken from our data capture system, will be compared, and adjusted if they differ, carrying out a supervised learning process.

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References

- [1] E. Garcia, N. Montés. Mini-term a novel paradigm for fault detection. IFAC-PapersOnLine (2019): 52-13, p. 165-170.
- [2] F. Chinesta, E. Cueto, E. Abisset-Chavanne, J. L. Duval, F. El Khaldi. Virtual, digital and hybrid twins: a new paradigm in data-based engineering and engineered data. Archives of Computational Methods in Engineering (2018) p. 1-30.
- [3] S. Dou and J. Xia. Analysis of sheet metal forming (stamping process): A study of the variable friction coefficient on 5052 aluminum alloy. Metals (2019): 9-8, p. 853.

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- [4] S. Berahmani, C. Bilgili, G. Erol, J. Hol, B. Carleer. The effect of friction and lubrication modelling in stamping simulations of the Ford Transit hood inner panel: a numerical and experimental study. In IOP Conference Series: Materials Science and Engineering (2020): 967-1, p. 012010. IOP Publishing.
- [5] Y. Tamai, T. Inazumi, K. I. Manabe. FE forming analysis with nonlinear friction coefficient model considering contact pressure, sliding velocity and sliding length. Journal of Materials Processing Technology (2016): 227, p. 161-168.
- [6] S. Olguner and A. T. Bozdana, The effect of friction coefficient on punch load and thickness reduction in deep drawing process. Int. J. Materials 3 (2016): 64-8.
- [7] M. Javadi, M. Tajdari. Experimental investigation of the friction coefficient between aluminium and steel. Materials Science-Poland (2006) 24(2/1), p. 305-310.
- [8] Y. Ledoux, P. Sébastien, S. Samper. Optimization method for stamping tools under reliability constraints using genetic algorithms and finite element simulations. Journal of Materials Processing Technology (2010) 210-3, p. 474-486.
- [9] C. Wang, R. Ma, J. Zhao, J. Zhao. Calculation method and experimental study of coulomb friction coefficient in sheet metal forming. Journal of manufacturing processes (2017) 27, 126-137.
- [10] M. Başpınar, M. Akkök. Modeling and simulation of friction in deep drawing. Journal of Tribology (2016) 138-2, 021104.
- [11] J. Lan, X. Dong, Z. Li. Inverse finite element approach and its application in sheet metal forming. Journal of materials processing technology (2005) 170(3), 624-631.
- [12] I. Peinado-Asensi, E. Garcia, N. Montés. Towards Real Time Predictive System for Mechanical Stamping Presses to Assure Correct Slide Parallelism. SciTePress, ICINCO, 2021.