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DESIGN OF A FORMING DIE USING CAX SOLUTIONS

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Abstract. *This study aimed to present a method to design a forming die, covering pre-dimensioning, 3D modeling, structural analysis by Finite Element Method, flattening of segments with complex geometry, drawing for manufacturing and the die machining. In order to explore the integration of the engineering solutions, CAD, CAE and CAM environments were used, which demonstrated feasibility to the product design cycle, allowing to develop, simulate and assist the machining process.*

Keywords: *Forming, Finite Element Method, CAD, CAE, CAM.*

1. INTRODUCTION

In the last decades, with the advance of computing and engineering software, the use of high-tech solutions has become strategical in the development of most diversified projects and products, allowing their use in practically all stages of the project life cycle, from conception to manufacturing.

In the forming industry, due to the complexity of the die design, the use of these solutions becomes particularly interesting. However, in many companies, the design of the dies is made based only on experimental and empirical knowledge, which generates a higher degree of insecurity and risk, and avoiding possible improvements in terms of safety, quality and reduction of manufacturing costs.

In this context, this work intends to show the use of computational engineering solutions and its benefits at the design of a forming die for pressing a spherical segment usually used in equipment such as pressure vessels. The pre-design of the die is made using CAD (Computer Aided Design), integrated to the structural validation using FEA (Finite Element Analysis). Aiming to assist the manufacturing, the work also includes the flattening of a complex geometry, the elaboration of manufacturing drawings, as well as the preparation of CNC machining programs (Computer Numerical Control) using CAM (Computer Aided Manufacturing). All the work is performed using the software Siemens NX 7.0 supplied by Siemens PLM.

2. CAx

CAx is used to refer to the various systems used in a wide range of applications, in order to assist in the design, analysis, validation, planning, control and manufacturing of products. Within this universe, the concepts of CAD, CAE and CAM stand out, widely used in different stages of the product's life-cycle.

2.1 CAD – Computer Aided Design

CAD comprehends the computational solutions used in order to develop projects, models, virtual representations and technical drawings. Among other areas, it has a strong application in engineering, architecture and design, allowing the elaboration of two-dimensional (2D) and three-dimensional (3D) drawings (Sacar et al., 2008), (Duggal, 2000).

CAD programs offer a series of tools, and generally within four environments: modeling; sheet metal; assembly; and drawing. Its use brings great benefits in terms of productivity and efficiency in the design, especially in the review and optimization of projects. In die projects, it is particularly suitable due to some benefits such as parametrization, integration with CAE and manufacturing, whether through CNC programming, communication with robots, among others (Sacar et al., 2008). Furthermore, there is already a tendency to incorporate new dimensions into CAD programs, such as the dimensions of time (4D) and costs (5D) to make it a more comprehensive tool.

2.2 CAE – Computer Aided Engineering

CAE is used to cover several computational analysis techniques, such as: structural analysis by the finite element method (FEM), thermal and fluid analysis by the computational fluid dynamics method (CFD), and analysis of dynamics and kinematics by multi-body dynamics (MBD). In addition, it includes solutions used for simulating manufacturing processes, such as casting, forming and stamping.

CAE solutions are usually used for simulation, validation and optimization of products and processes (Raphael and Smith, 2003). Basically, the execution of the CAE simulation is divided into three steps, which can be repeated as a cycle for optimization as many times as it requires, being the steps:

- Pre-processing: definition of the mathematical model (usually imported from a CAD software), materials, boundary conditions and mesh preparation.
- Processing: performed by the solver, where high computational processing performance is normally required.
- Post-processing: display and analysis of results, using graphic visualization resources.

The use of this technology has made it possible to achieve a great reduction of costs and time in product development, especially regarding to the manufacturing of prototypes, which are still demanded, however now are more required for validation purposes.

2.3 CAM – Computer Aided Manufacturing

CAM refers, in a broader concept, to the use of computational solutions to assist any operation of a manufacturing plant (US Congress, 1984). Some common examples are the development of programs for machining and cutting parts, programming robots and 3D printers.

In the software interface it is possible to input all the necessary information for the machining operations, such as the type and geometry of the tool, the cutting parameters, the selection of the type of operation (roughing or finishing), the pattern of the tool path and components for checking interference (collision). After these parameters being established, the software generates the necessary tool paths for the execution of the machining operations. The last step is to generate the program in the machine language, which demands the use of a post-processor with the CNC code specific to the machine adopted.

In die design, the use of this technology, combined with CAD and CAE solutions, has provided great advances in terms of productivity and quality in manufacturing processes. It allows the elaboration of highly complex programs, through functionalities that makes it possible the visualize, simulate and optimize manufacturing operations.

3. MATERIALS AND METHODS

3.1 Workpiece

The workpiece to be conformed is a spherical segment, shown in Figure 1, made of structural steel ASTM-A36. This type of piece is used in several equipment, such as pressure vessel heads, and can be designed in different dimensions, shapes and materials. Likewise, the methodology presented in this work can be applied in the conception of dies for different designs of pieces, except by making some adjustments.

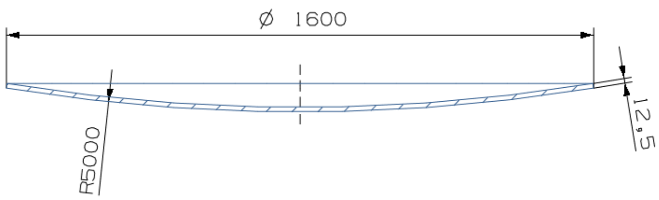

Figure 1 – Cross section view of the workpiece.

Table 1 presents the mechanical properties of the ASTM-A36 structural steel with no special requirements, often used in the manufacture of less responsible devices and dies.

Table 1 – Properties of the die material at room temperature (Usiminas, 2015), (Siemens, 2009).

ASTM-A36 Structural Steel - Isotropic	
Young modulus E	2,1 GPa
Poisson’s ration v	0,298

Yeld Strengh YS	250 MPa
Ultimate Strengh US	400 MPa
Safety Factor SF	2,5[1]
Permissible Stress PS (PS = YS/SF)	100 MPa

[1] Proposed by the authors.

3.2 Software and Hardware

The proposed work requires the use of CAD, CAE and CAM tools. It was chosen the software Siemens NX 7.0, as it presents all these features integrated on the same platform. However, many other solutions available on the market could have been chosen without any significant losses to carry out this work. The hardware used consisted of a computer with Windows 10 operating system, Intel Core I7-8565U CPU @ 1.80GHz 1.99GHz, with 16GB of installed RAM, dedicated NVIDIA GeForce MX150 graphics card, and 258GB SSD.

4. RESULTS

4.1 Pre-design

The die developed for forming the part consists of two parts called the upper and lower die, as shown in Figure 2.

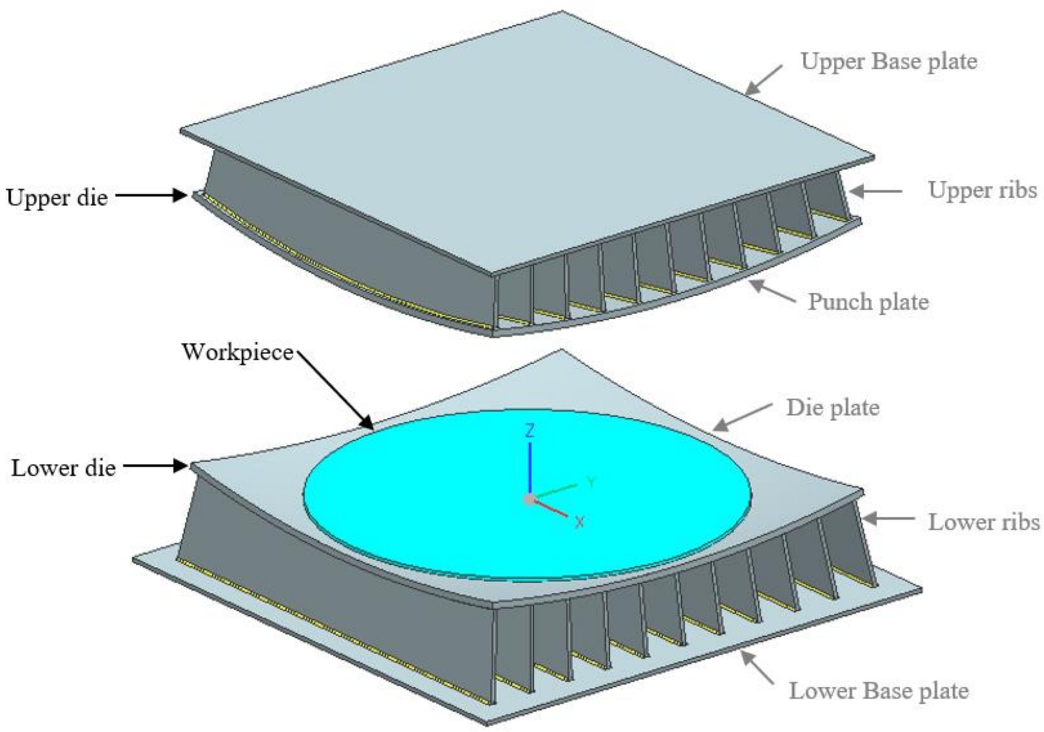

Figure 2 - Upper and lower Die.

The pre-adopted dimensions for the matrices are presented in Figure 3. The dimensioning of the matrix was done empirically, with some considerations:

a) The thickness of the plates and ribs were initially adopted equal to the workpiece thickness ($e_{fs} = e_{fi} = e_{bs} = e_{bi} = e_{ns} = e_{ni}$ = 12,5mm), where e_{fs} = thickness of the punch plate, e_{fi} = thickness of the die plate, e_{bs} = thickness of the upper plate base, e_{bi} = thickness of the lower plate base, e_{ns} = thickness of the upper ribs, e_{ni} = thickness of the lower ribs.
b) 11 ribs were used in each die equally spaced.
c) A minimum height of 200mm was adopted in the ribs.

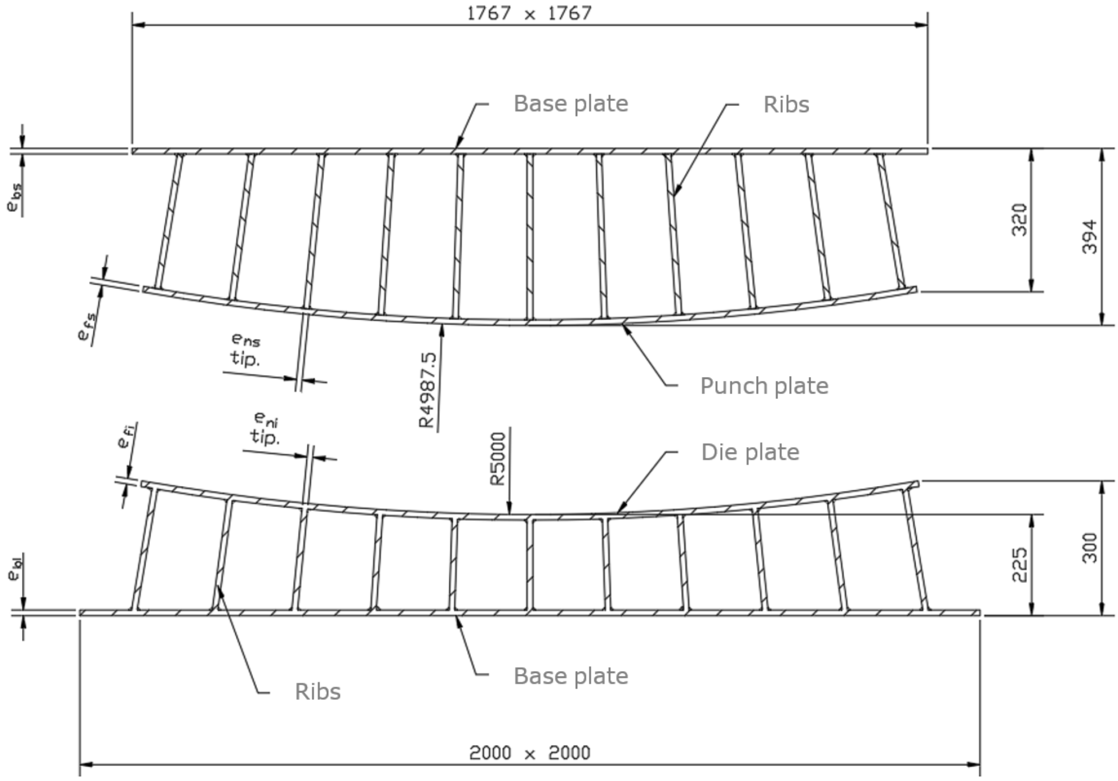

Figure 3 – Section view of the upper and lower dies.

The 3D modeling of the dies was done in a parametric way, in order to allow changes on the initially adopted parameters if the pre-dimensioning if them are satisfactory in the finite element analysis. Next, the detailed study carried out for the lower die will be presented. The same procedure was performed for the upper die, which won't be presented on this paper since the results are very similar to those of the lower die.

4.2 Analysis of the stress on the die due to forming forces

The input parameters and simulation information are shown in Table 2.

Table 2 – Simulation parameters and information.

Software Siemens NX - Design Simulation	
Solver	NX Nastran Design
Type of simulation	Structural
Type of analysis	Static linear

Due to the symmetry of the lower die, only a quarter of the matrix was simulated, and the boundary conditions of symmetry were adopted in the planes YX and XZ, as shown in Figure 4.

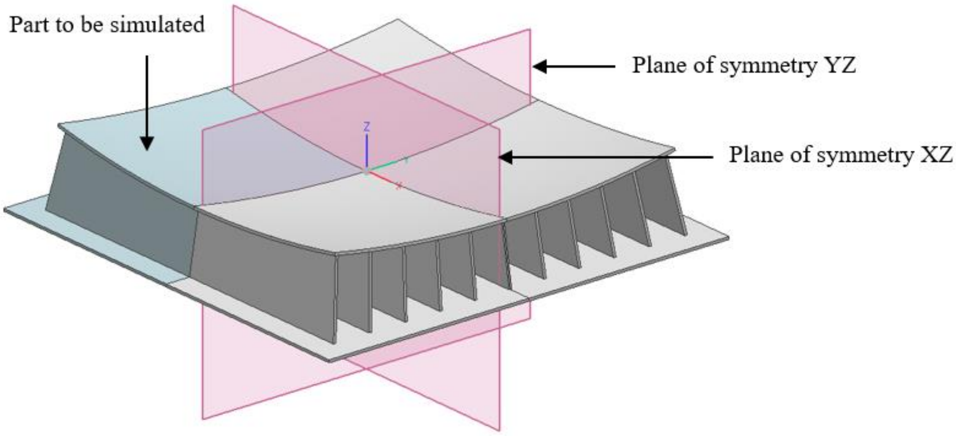

Figure 4 – Section planes of symmetry.

The boundary, symmetry and mesh conditions are shown in table 3 and figure 5.

Table 3 - Imput data.

Boundaury conditions and mesh	
Load (force along Z axis)	10.000kN
Boundary conditions	Base plate fixed
	Symmetry on planes XZ and YZ
Mesh	
Type of element	Tetrahedron
Average size of element	12.5mm

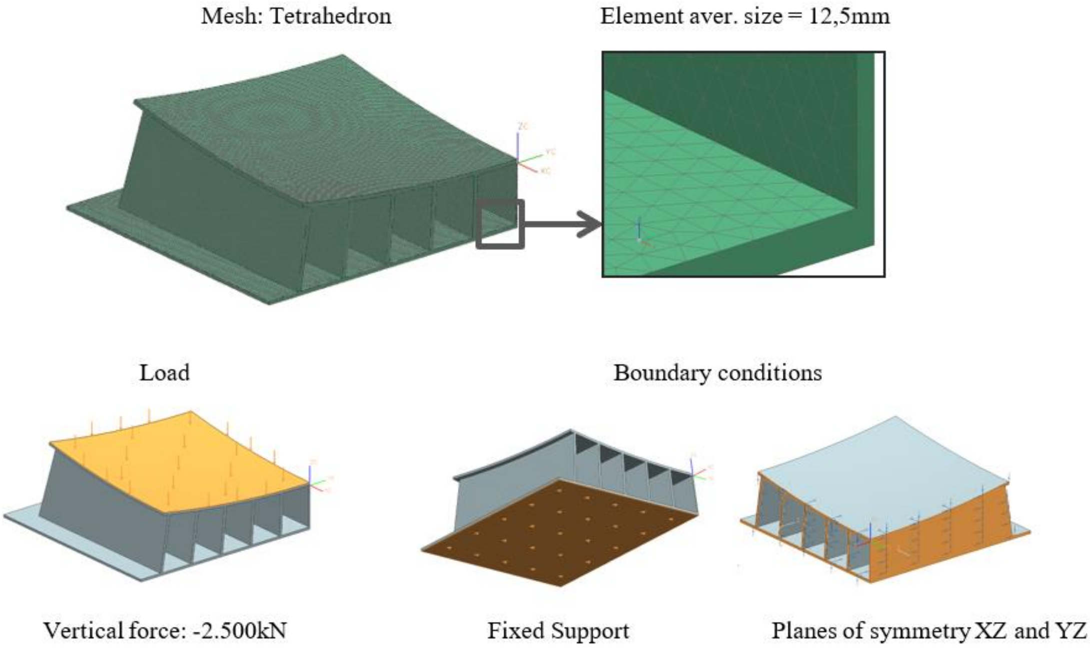

Figure 5 - Mesh, loads and boundary conditions.

The simulation results are shown in Figure 6. An average stress of 40 MPa was found in the ribs, and peak stresses of 75 MPa were found on the surface of the die plate close to the ribs, being these lower than the permissible stress of 100MPa.

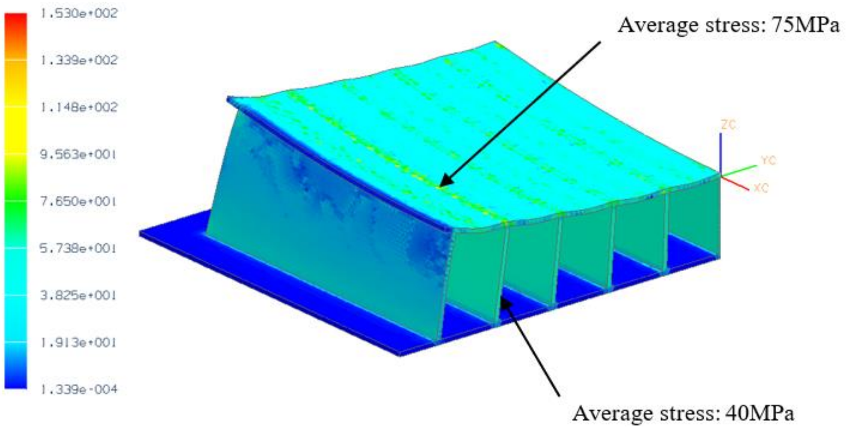

Figure 6 - Von Misses Stress on the lower die.

Figure 7 shows the areas where the stress exceeded the adopted permissible stress of 100MPa. Since the material used features a yield strength of 250 MPa, and these stresses are located in small areas, those were considered acceptable.

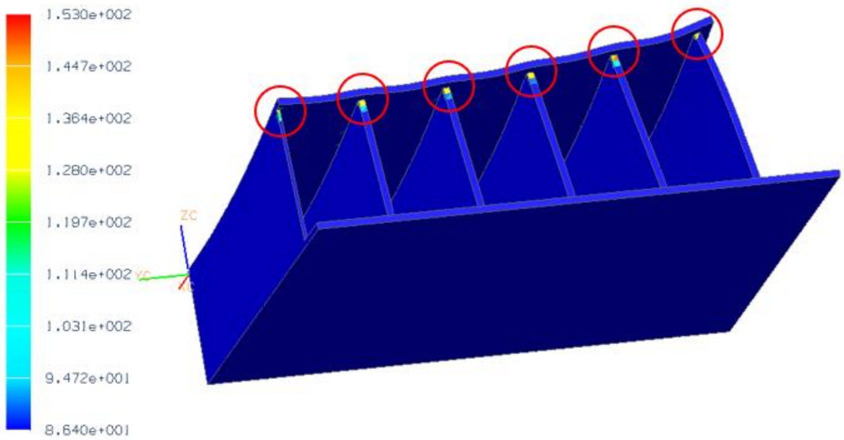

Figure 7 – Areas where the values overpassed the permissible stress.

Figure 8 shows the result of the first failure mode on the buckling analysis, where it was found that it occurs on one of the ribs, for a loading with a magnitude of approximately 77 times the load applied. This shows that the height adopted on the predesign (200 mm) satisfies the working conditions with a satisfactory safety factor.

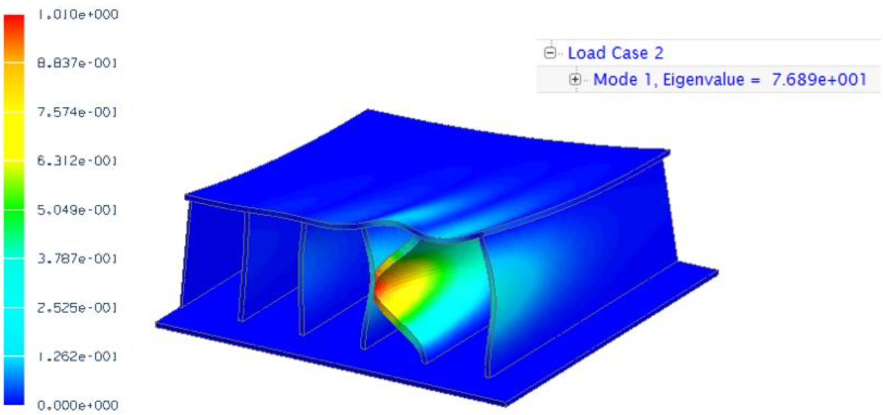

Figure 8 – Buckling analysis – first mode of failure.

Finally, Figure 9 shows the results of displacement of the die as a function of the loads considered for conformation. It was observed that the largest deviations occurred in the span between the ribs, with values between 0.1mm to 0.19mm. Based on the workpiece application and its manufacturing tolerances, besides assuming that only part of the die deflection will be transferred to the workpiece, these displacements were considered acceptable.

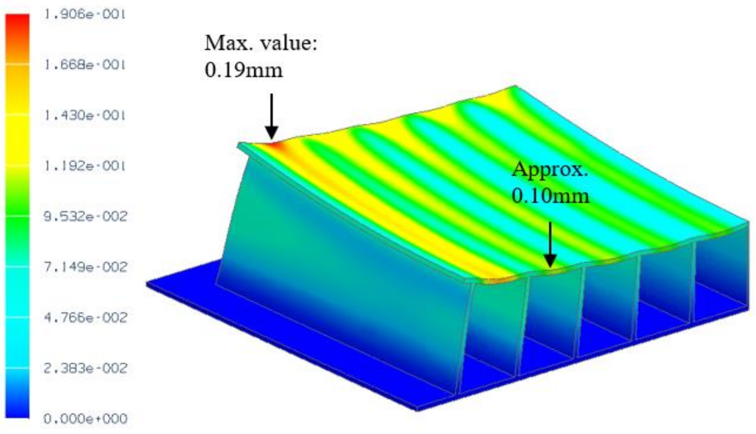

Figure 9 - Displacements results.

4.3 Flattening

Since the punch and die plates are spherical segments, it is necessary to flat them to obtain the dimensions of the plates before being shaped. Since it is a complex shape for flattening, this step was performed using the NX software, with the Metaform tool of the Sheet Metal module.

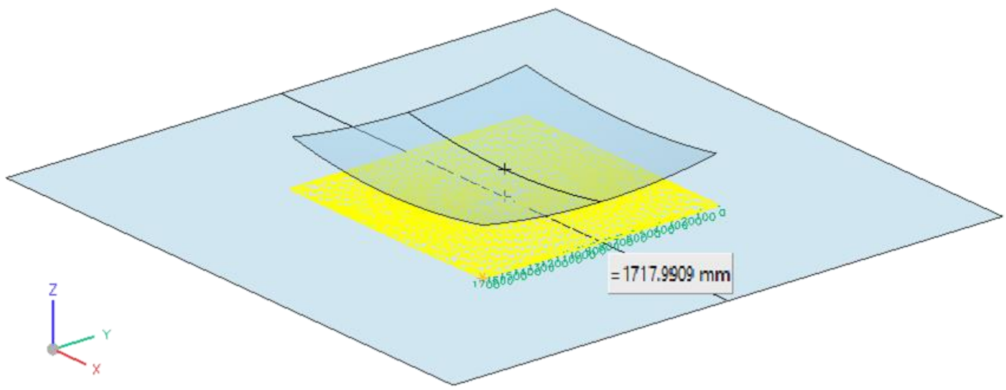

Figure 10 – Flattening of the die plate.
Mesh parameters: triangular shell elements with length between 100 mm to 150 mm.

4.4 Weld

The welds were modeled in a parametric way, in order to facilitate the calculation of the consumable volume. In this case, the weld fillets were dimensioned based to the thickness of the ribs. This concept allows the size of the weld fillets to be updated depending on the changes on the thickness of the ribs. However, after validating the model by FEA, it is necessary to carry out the dimensioning of the welds.

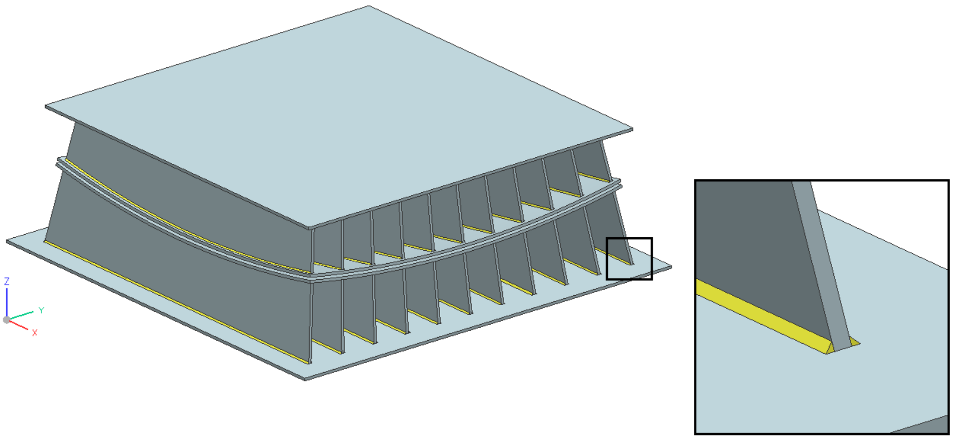

Figure 11 – Design of the weld fillets.

4.5 Drawings

The drawings for manufacturing are obtained through the 3D model, from which it is possible to create detailed sheets in the drawing environment. From the drawings, it is possible to prepare the cutting plan of the pieces using nesting software such as Sigmanest.

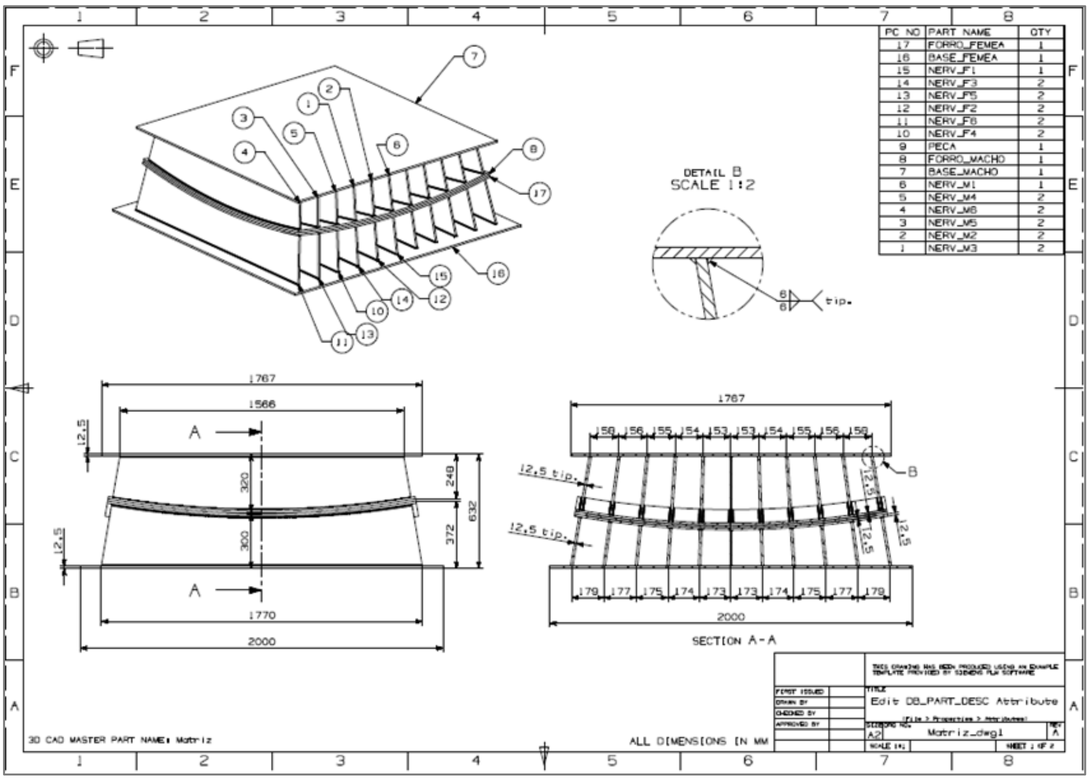

Figure 12 - Die assembling drawing.

4.6 Die and punch plate forging

For shaping the punch and die plates during the manufacturing, the die base itself can be used as shown in Figure 13. The flat sheets of the punch and die plates are placed between the ribs, and then the hydraulic press is activated to make them conform assuming the die shape. Due to the gap between the finished profile of the punch and die plate, a blank plate is used. After forming the plates, with the parts still in the press, tack welds are performed to keep the plates fixed in the die in the correct shape (avoiding the spring back). After removing the die from the press, the complete welding of the ribs in the plates must then be carried out.

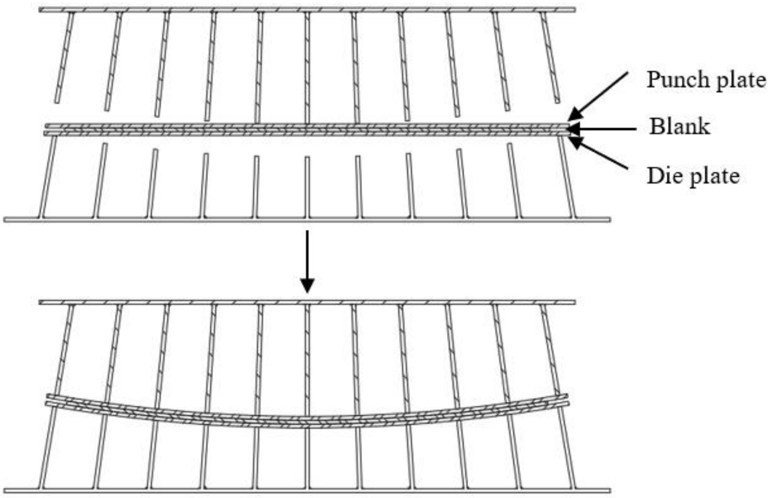

Figure 13 - Forging of the punch and die plates.

4.7 CNC program for machining

To ensure the correct geometry of the punch and die plates, it is necessary to perform the machining on their surfaces. In this case, due to the simple geometry of the surface (spherical), a 3-axis milling operation can be performed. Then, a stock of 5 mm was considered on the surface to be removed on two operations: roughing and finishing. The configuration performed in the software and the machining data are shown in table 4. It is important to note that the machining values adopted, such as cutting speed and feed are empirical, thus it must be adjusted according to the tool supplier instructions.

Table 4 - Parameters used on the milling setup - NX Manufacturing.

Milling parameters - NX manufacturing	
CAM type	cam_general
CAM setup	mil_contour
Operation	contour_area
Method	surface area
WCS (work coordinate system)	As shown in Figure 14
Cutting Pattern	Helicoidal
Spindle axis	Z
Stock	5mm
Approaching	Linear
Cutting speed	100m/min
Feed (per cutting edge)	1mm
Spindle speed	318 rpm
Number of cutting edges	8
Feed speed	2544mm/min

The roughing tool adopted was a milling head with ø100mm, and with 8 carbide cutting inserts and insert radius of 10 mm. For finishing, a similar tool was considered with a diameter of 50mm.

Figure 14 shows the simulation of the machining of the surface of the die plate, in which the tool approaches in a linear mode through the center of the die plate (yellow line), and then moves helically (cyan lines) from the center to the periphery of the die, removing the stock. The cutting parameters are indicated in Table 4. Passive movements of the tool are indicated by the colors blue and red.

After simulating the machining operations, and checking for possible collisions, the program can then be generated in the machine language using the post-processor. The NX software offers some pre-configured ISO machine codes post-processors, such as 3, 4 and 5 axis milling machines. In addition to those, if necessary, it is possible to develop a specific post processor for a given machine code.

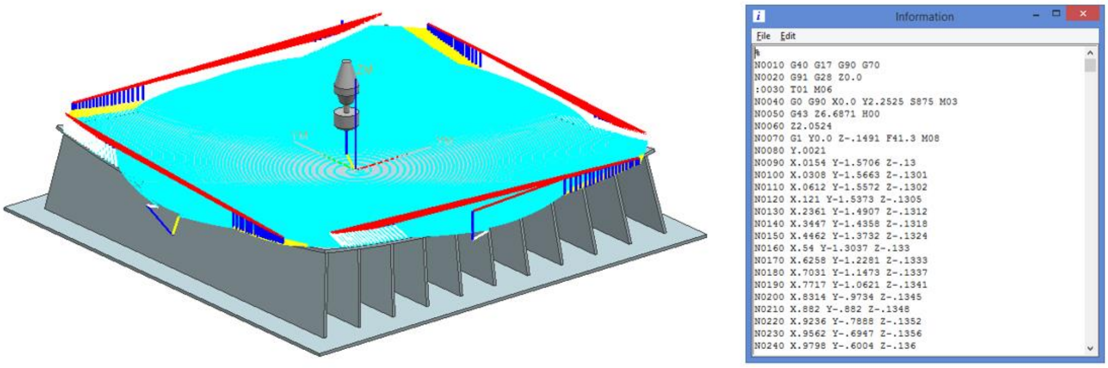

Figure 14 – Machining simulation and CNC program created.

5. CONCLUSIONS

This work aimed to demonstrate a method for designing a conforming die using CAx tools. The software NX V.7.0, made available by Siemens PLM, was used. This work covered the following topics:

- Pre-dimensioning and 3D modeling
- Structural analysis and segments flattening with FEA
- Drawing's construction
- CNC programming for machining

Some factors were not covered in this study, such as the prediction of the spring back effect in the die design, simulations referring to the part's conformation and sizing the weld. In addition, due to the similarity between the upper and lower dies, only the lower die design was demonstrated in this work.

6. ACKNOWLEDGEMENTS

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