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Simulation of Porthole Die Extrusion Process comparing NEM and FEM modelling

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Abstract. Porthole die extrusion is a process typology that can give great advantages in the forming processes. Due to the complexity of the die assembly, experimental analyses are often carried out in order to investigate the parameter influence on the quality of the final parts.

Finite Element Analyses, however, have been often used for the cost reducing and for a better local investigation of variables like pressure and effective stress inside the welding chamber.

In spite of that, up to now, commercial FE codes present a “structural” limit during the welding phase due to the impossibility to simulate element joining when material reaches the required process conditions.

From this point of view, the Natural Element Method (NEM) provides significant advantages; in fact, the meshless characteristic of NEM is “natively” able to simulate joining of free surfaces, as it occurs during porthole die extrusion, simulating the welding line formation inside the welding chamber.

In this paper, using experimental tests recognizable in literature, the authors tried to validate the effectiveness of this technique; moreover, even a comparison between NEM and FEM results was carried out.

More in detail, different geometries of the welding chamber were analyzed; in some cases, the process conditions were suitable to guarantee material welding while, in other cases, the material came out from the porthole die without joint formation. The variable that was used to verify the process goodness is the maximum pressure inside the welding chamber.

Furthermore, to evaluate the effectiveness of 2D analyses, even in a complex shape, a significant section was extrapolated for each die, performing a NEM vs. FEM assessment of the results.

A good comparison was obtained between the two different methods that, moreover, were in agreement with the experimental tests.

Introduction

Extrusion welding is a process that generally is characterized by co-extrusion of two or more metals [1] or, even, by different flows of the same metal. In the last case, the material undergoes an initial splitting phase due to a suitable porthole and, subsequently, a joining phase inside a so called welding chamber. The process, usually, is conducted at elevated temperature not only to improve welding, but even to reduce the required pressure inside this chamber.

Different aluminum alloys have been worked through this technique; at now, in fact, the investigated process is physically possible with all wrought aluminum [2].

Diverse geometrical and process parameters have to be, however, considered in order to improve the quality of the welding lines and, consequently, the goodness of the worked parts. In the technical literature, several works have been carried out to highlight the influence that die design has on the extrusion process [3-4]. From this point of view, the analysis of the metal flow in the

porthole die extrusion results to be fundamental and its optimization can lead to an high process performance [5].

Different variables have been taken into account in order to predict the quality of welding line; however, substantially, the effective stress, the pressure and the time that the material spends to cross the welding chamber are the greatnesses usually monitored [6].

Moreover, the temperature is another important variable that has to be properly considered; from this point of view, a relationship between temperature and limit welding values was proposed [7] using the Pivnik and Plata criterion [8] for representing the conditions at which solid state welding occurs.

To optimize the process, experimental and numerical studies have been carried out [9-11]. However, due to the porthole die complexity, experimental analyses usually require time consuming for the equipment construction and, besides, it results to be expensive to verify different geometrical solutions. From this point of view, simplified equipments were proposed in literature [12].

On the other part, the FE simulations can overcome the above presented limitations but, due to the great mesh distortions, the obtained results can be deeply affected from remeshing phases. Furthermore, at now, the joining phase cannot be simulated using commercial codes and this aspect represents an important limitation for the process analysis.

The natural element methods (NEM) can be adequately used in this context according to the highlighted issues. This technique, in fact, presents those advantages, such as no remeshing requirements for the accuracy of the approximation and capacity to simulate the creation and joining of free surfaces, fundamental for welding extrusion. Moreover, it is also possible to detect and simulate the formation of welding lines checking if the process conditions are enough to guarantee the welding conditions.

In the study here proposed, experimental and numerical comparison was proposed. More in detail, experimental data, found in literature [13], were used in order to validate the numerical results.

Both FE and NE methods were used in order to simulate the process starting from 2D analyses; for this investigation, a significant section was extrapolated by the complete die.

Finally, even a 3D numerical study was carried out and the comparison of results was reported.

The Experimental Data

The production of special H profiles was taken into account. The used die was reported in Fig. 1.

Fig. 1: Geometry used in the experimental analysis.

The experimental investigations were carried out by Valberg et al. [13] for the manufacturing of the demonstrated profile with different welding chamber dimensions. Several geometries were considered in order to modify the process conditions along the welding plane; in this way, the material joining was more or less favoured.

For the work here proposed, just four die designs were investigated trying to analyze both cases that lead to sound and unsound parts. More in particular, the tests numbered with 1, 4, 7, and 9 were taken into account; their geometrical differences were reported in Table 1.

Table 1: Geometrical differences and results of the analyzed experiments [6]

Experiment No.	Tongue h/b/angle	Extrusion ratio	Optical analysis	Welding chamber
1	17/5/90°	25.6	-	Fill
4	17/5/45°	25.6	-	Fill
7	10/3/90°	28.9	No welded	No Filling
9	10/3/45°	28.9	Unwelded stripes	Gas Pocket

The other geometrical variables and process conditions were, instead, fixed and their influences were not discussed in the work.

The study was carried out extruding an AA6082, an aluminium alloy that presents relevant industrial applications.

Numerical Analyses

Both FEM and NEM results were conducted and their results were compared with the experimental ones. In this phase, isothermal analyses were carried out in order to reduce the computational time fixing the billet temperature to 510°C; the model simplification can be justified considering that along the welding plane the material presents a narrow temperature variation.

An equation relating the hyperbolic sine of flow stress to the temperature modified strain rate was used to describe the AA6082 flow behavior [14].

The effectiveness of NEM analyses from this process typology was tested starting from a 2D study (Fig. 2).

Fig. 2: 2D section extracted by 3D model.

This analysis typology, obviously, cannot be used for a comparison with the experimental data due to the complexity of the 3D model; however, the extrapolated results are meaningful for validating NEM goodness in 2D studies. The successive 3D simulations, in fact, result to have a more truthful physical meaning but, obviously, to detriment of computational time.

The 3D study was, moreover, conducted taking advantage of a symmetry plane that let to study just $\frac{1}{2}$ of the real geometry.

Furthermore, for an additional simulation time reduction, just the billet was meshed while punch, porthole die and welding chamber were considered like rigid bodies. Finally, adhesion was considered between dies and forming material [6]. So doing, the shear stresses are probably over-estimated at low values of contact pressure, but, this condition was adequately validated [15].

FE Analyses. The numerical analyses were carried out using the commercial code numerical SFTC Deform. The 2D and 3D simulations were set with the extruded billet which was meshed using suitable mesh boxes in order to reduce the element dimensions close to the die edges and inside the welding chamber (Fig. 3).

Fig. 3: a) 2D and b) 3D model used for FE analyses.

NE Analyses. The principal characteristic of this method is that it is a Galerkin procedure that relies on natural neighbor interpolation to construct the trial and characteristic test functions.

The starting point is a model composed by a cloud of points $N = \{n_1, n_2, \dots, n_m\} \subset \mathbb{R}^d$, for which the space decomposition into regions is unique; more in detail, each point within these regions is closer to the node to which the region is associated than to any other in the cloud. This decomposition is known as Voronoi diagrams of the cloud of points; each Voronoi cell is formally defined as Eq.1:

$$T_I = \{x \in \mathbb{R}^d : d(x, x_I) < d(x, x_J) \forall J \neq I\} \quad (1)$$

In Eq.1 $d(., .)$ is the Euclidean distance function; two nodes that share a facet of their Voronoi cell are called natural neighbours.

The dual structure of the Voronoi diagram is the Delaunay triangulation; nodes that share with a specific node an edge of a Delaunay triangle (2D) or tetrahedron (3D) are defined its natural neighbours.

In the NEM framework, different interpolants have been proposed. The original version of the method [16] employed natural neighbour (Sibson) interpolation [17]. This one is very well-known in the approximation community as a high-quality interpolation scheme with a lot of advantages [18]. Sukumar [19], subsequently, proposed the use of Laplace (also known as non-Sibsonian) interpolation [20]. The last one, used in this paper, is considerably less costly than the original Sibson interpolation, although somewhat less smooth.

The extrusion of hollow profiles presents further difficulties for NEM due to free surface flows; in fact, for a correct process study results to be fundamental to track accurately the surface position. Since meshless methods only use clouds of nodes, shape constructors, which are geometrical entities that give a continuous shape to a discrete cloud of nodes, have to be introduced. One of

such constructors, used in the proposed models, is the family of α -shapes [21]. The use of a proper α -shape for the definition of the domain ensures the linear interpolation of the essential field along the boundary [22].

The 2D and 3D models used for NE analyses are reported in Fig. 4.

Fig. 4: a) 2D and b) 3D model used for NE analyses.

Result Comparison

The variable that was taken into account in order to judge the quality of the obtained results was the maximum pressure inside the welding chamber. This is the criterium proposed by Akeret [23] that is the easiest and, perhaps, clearest criterion, to evaluate the weld quality; it states that if the monitored pressure exceeds a critical value, obtained by experimental tests, the welding can be considered correct.

2D Numerical Results. FE and NE comparison for the chosen section are shown in Fig. 5.

Fig. 5: Pressure distribution inside a section of welding chamber for a) FE and b) NE analyses.

The range of pressure inside the welding chamber, predicted by two different analyses, shows a good comparison; more in detail, along the welding plane, the pressure results to be slightly slow for the NE analysis. Besides, it is important to highlight how in the NE representation, there is not a separation line between the two material flows that, instead, it is present in the FE analysis.

To tell the truth, in literature, a special procedure was illustrated in order to guarantee the element joining for FE method [24]; it uses geometrical considerations and, for 3D real case, it was, at now, still never implemented due to its complexity.

Fig. 5 is referred to the experiment n°4, but the some consideration can be done even for the other investigated cases. From this point of view, it resulted to be very interesting the comparison among the pressure variations obtained by NEM for the four different geometries (Fig. 6).

The predicted trends seem to be, qualitatively, close to the experimental results; in fact, the high value was observed for the section extracted from die 4 while the worst condition was recorded for the section referred to the small welding chamber (die 7). The others two geometries, instead, showed an halfway distribution that can be comparable.

Fig. 6: Pressure distribution inside welding chamber for section extracted from a) 1, b) 4, c) 7 and d) 9 experimental tests.

3D Numerical Results. In order to compare the results derived from the different FE and NE analyses, even for the 3D cases, the experiment 4 was taken into account (Fig.8).

Fig. 8: Pressure distribution (exp. 4) inside the welding chamber for a) FE and b) NE study.

The pressure range inside the welding chamber showed a good comparison. However, for 3D study, the importance of element joining has to be more emphasized; in fact, for the finite element code the interaction between two material flows is very complicated to manage and, even using a suitable billet discretization, the welding zone is characterized by jagged surfaces (Fig. 8) that make, in these zones, the results rather arguable.

The pressure distribution for the two die geometry characterized by larger tongue ($b=5\text{mm}$) were compared in Fig. 9. The other two cases, due to the narrower die gate, require a finer billet discretization; for this reason, their results will be proposed in a future work.

Fig. 9: Pressure distribution inside welding chamber respectively for a) 1 and b) 4 experimental tests.

The results obtained from 2D analyses were qualitatively confirmed for the reported 3D analyses; in fact, an higher pressure was recorded for the die related to experiment 4. Furthermore, the experimental data were validated, too; in fact, the pressure in the welding chamber changes passing from about 80 MPa for the experiment 1 to about 110 MPa for the most suitable die (experiment 4). This variable, actually, presents a certain variability; more in detail, the punctual value was established taking into account the zone below to the die bearing.

Conclusions

A comparison between FE and NE results was carried out analyzing a porthole die extrusion process. The investigated material was an aluminum alloy, AA 6082, that presents great industrial relevance; in order to validate the obtained results, an experimental campaign, found in literature, was utilized.

A good agreement between the two different numerical analyses was observed and, for the 3D study, an acceptable correspondence with the experimental data was registered.

The great advantage of NEM is, above all, due to the material flow joining that allows a welding plane formation carrying out numerical analyses closer to the real process.

Moreover, due to this aspects, the results in this zone are no influenced by frequent remeshing and jagged surfaces that are, instead, typical for a FE analysis.

Different problems, however, have to be still tackled for increasing the NE potentiality; in fact, at now, the long simulation time and its set-up complexity represent significant drawbacks that have to be considered and improved for considering the NE techniques useful for forming process optimization.

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