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Hot Extrusion Technology Generation on the Basis of FEM and FMEA Analysis

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Evaluation of risks through application of FMEA methods, give answers and conditions for an analysis which decisively affects adoption or rejection of technological and structural solutions. This is, primarily, a team-oriented dynamic method based on a multidisciplinary approach to the problem solution by FEM modeling. The primary goal is to reduce risk of errors occurring in the development and design process of new aluminium products, both in the tool design process, CAD, and in the very process of plasticity deformation by forward hot extrusion technology. It is FMEA which documents knowledge of experts in a company, and it becomes its property, gaining in value and topicality with each passing day. This was perceived by the most powerful global companies in all the fields of management technology and they solved their problems leaving nothing to circumstances or time.

Generiranje tehnologije toplog istiskivanja na osnovu FEM i FMEA analize

Izvornoznanstveni članak

Procjena rizika primenom FMEA metoda daje odgovore i uslove za analizu koja presudno utječe na usvajanje ili odbacivanje tehnoloških i konstruktivnih rešenja. To je prije svega timski orijentirana dinamička metoda zasnovana na multidisciplinarnom pristupu u rješavanju problema FEM modeliranjem. Prvobitni zadatak je da smanji rizik od nastajanja grešaka prilikom procesa razvoja i projektiranja novog proizvoda od aluminijuma, kako u procesu projektiranja alata, CAD, tako i u samom procesu plastične deformacije postupkom istosmjernog istiskivanja.
Upravo FMEA dokumentuje znanje eksperta u kompaniji i to postaje njena svojina koja svakim danom dobija na vrijednosti i aktuelnosti. To su najmoćnije svjetske kompanije u svim oblastima upravljanja tehnologijom odavno uočile i probleme rješavale ne prepuštajući ništa slučaju i vremenu.

1. Introduction

The complete and high technology extrusion system of half-hollow elements is based on a design process as well as realistic parameters and indicators that have a decisive impact on the course of an extrusion process. Offering a possibility to collect and describe numerical values and analyze feedback informations, both from the production process itself and from design and development process, on errors, deficiencies and remarks, generate an adaptive dynamic system in the time [7, 11, 18].

2. Management technology and level of failure

As this is a series of consecutive technologies (aluminium foundry, heating, forward extrusion, assembly, recycling etc.), mutually-connected so that a high quality of the final products could be achieved, perceived errors can occur in the very forward extrusion process of half hollow elements, but they can also be caused by previous production procedures [11]. In this way their influence is accumulated, and only at the end of the production process is it manifested as a key deficiency which cannot be rectified (e.g., poor quality of aluminium in the foundry process will result in waste casting which would not allow high quality extruded elements).

The perception of error in such a mega process must be understood very widely, as it is possible in various levels. Namely, the errors made by company management in creating the business policy of the company and the entire business can have decisive effects on the survival of the entire company and vice versa. Making a right decision and a business solution would surely result in a positive

Symbols/Oznake

t	- process temperature, °C - temperatura procesa obrade	v^*	- virtual velocity field, m/s - virtualno polje brzina
p	- pressure, MPa - tlak	p^*	- virtual pressure, MPa - virtualni pritisak
s	- deviatoric part of stress tensor, MPa - devijatorni dio tenzora napona	dV	- element of volume deformation, m^3 - element deformabilne zapremine
σ^t	- stress tensor at the moment t, MPa - tenzor napona u trenutku t	dS	- element of contact surface, m^2 - element kontaktne površine
τ	- shear stress, MPa - smičući napon	$g(x^t, t)$	- contact surface of the tool at time t - kontaktna površina alata u trenutku t
$\dot{\varepsilon}^*$	- virtual strain rate tensor, s^{-1} - virtualni tenzor brzina deformacija	$g(x^{t+\Delta t}, t+\Delta t)$	- contact surface of the tool at time $t+\Delta t$ - kontaktna površina alata u trenutku $t+\Delta t$

outcome. It is certain that analysis of errors at the top level is a much bigger challenge and requires a particular approach to the problems. On the other hand, the errors occurring within the production processes are far less serious and can be corrected relatively easily. Such errors are the most dangerous if they are left unattended; if they are not detected immediately and they tend to accumulate. For a simple reason, their early detection launches corresponding sub-processes and procedures which then prevent errors, and minimize the financial damage of the error. However, if such errors remain undetected in good time, they can incur huge financial losses and damage the company's image for a long period. This is particularly true in an environment of a dynamic market production requiring small series of products with new and very diverse requirements [11, 18].

3. Generate technology of forward extrusion process of half hollow element

Management and generate of new product as of aluminium and their alloys involove beside rest modeling of metal flow process and fulfill of tool in the area of die (H13, t = 420 ºC) and orifice involve interaction between the process variables and the material's high temperature properties (AA6060, t = 480 ºC). There are meaning change of cross section from workpiece to finished part (Figure 1) which follow high deformation degree, variable friction coefficent, temperature change, stress, strain, strain rate, etc. The process of forward extrusion for elements with complete cross section does not matter this investigation. Again, process of forward extrusion for half hollow elements of aluminium, that is more complex and precise geometry, is object this paper [5, 8, 13-14, 16-17].

Figure 1. Model of finished part and appropriate tool die

Slika 1. Model gotovog dijela i odgovarajuća alatna matrica

A commercial FEM package FORGE2® Transvalor was used to simulate the forward extrusion of hot aluminium. As a reason for the high extrusion ratio, a high deformation degree occurs with variable friction coefficients, temperature changes and variable stress and strain rate values. The data structure of the software program include governing equations, the finite element of the workpiece, rheology of the material, tooling description, frictional interface, and numerical parameters.

An accurate way to impose all these conditions is to use the mixed velocity-pressure formulation, which is given for any virtual (*) velocity field v^* and any pressure p:

$$\int_{\Omega} s : \dot{\varepsilon}^* \mathrm{d}V - \int_{\partial\Omega_c} \tau \cdot v^* \mathrm{d}S - \int_{\Omega} p\, div\left(v^*\right) \mathrm{d}V = 0, \qquad (1)$$

where s is the deviatoric part of stress tensor, $\dot{\varepsilon}^*$ the local strain rate tensor, dV the element of volume deformation, dS the element of contact surface between tool and billet and τ denotes the tangential stress on the contact zone. The weak form of the incompressibility constraint results in:

$$\int_{\Omega} p^* div\left(v\right) \mathrm{d}V = 0, \qquad (2)$$

where p^* is the virtual pressure. The program uses implicit FEM to calculate the hot working parameters: load, strain rate, temperature field and deformation. A Lagrangian method is adopted for the program which can thus accurately define the material properties, state variables and boundary conditions [2-4].

To properly model the complex interaction between tools and boundary of the billet, the surface of the tool is defined by the equation $g(x,t)=0$, while $g(x,t)>0$ represents the interior of the extrusion tool. The incremental contact conditions take into account three different cases:

1. transition may occur between free surface and contact

$$\begin{aligned} &g(x^t,t)<0, \quad (\sigma^t \cdot n)\cdot n = 0 \quad \rightarrow \\ &g(x^{t+\Delta t},t+\Delta t)=0, \quad (\sigma^{t+\Delta t} \cdot n)\cdot n < 0, \end{aligned} \qquad (3)$$

2. sliding contact

$$\begin{aligned} &g(x^t,t)=0, \quad (\sigma^t \cdot n)\cdot n < 0 \quad \rightarrow \\ &g(x^{t+\Delta t},t+\Delta t)=0, \quad (\sigma^{t+\Delta t} \cdot n)\cdot n < 0, \end{aligned} \qquad (4)$$

3. contact can be lost during increment

$$\begin{aligned} &g(x^t,t)=0, \quad (\sigma^t \cdot n)\cdot n \le 0 \quad \rightarrow \\ &g(x^{t+\Delta t},t)<0, \quad (\sigma^{t+\Delta t} \cdot n)\cdot n = 0, \end{aligned} \qquad (5)$$

where n is the normal of surface, σ^t the stress tensor at the moment t and x^t the point coordinate at the moment t.

To control the degree of remeshing in the areas where high deformation is expected, fine refinement mesh boxes of the Eulerian type (but maintaining Lagrangian flow) were applied to the billet. The remeshing values are controlled by the average target size of an element and the distribution is specified by mesh-boxes, i.e. boxes that define regions of the mesh on which a mesh size is imposed during computation (Figure 2) [1, 14].

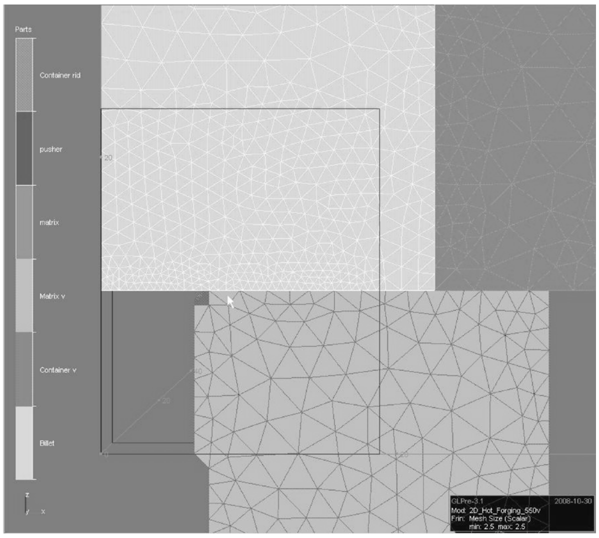


Figure 2. Mesh box in area of plasticity deformation

Slika 2. Mreža u oblasti plastične deformacije

The simulation approach is based on a viscoplastic constitutive model which neglects the elastic behaviour of the metal in a working process.

The meshing is based on two concepts: the quality of the elements and shape geometry. During the simulation of forward extrusion, large deformations are predominant which require a Lagrangian mesh to be defined. Thus, complete remeshing is mandatory in areas of excessive deformation of volume [2–3, 14].

The temperature field in the meridian cross section of the billet (from 549.5 °C to 450.6 °C on contact surface with tool), die and container indicates their interaction and heat transfer from billet to tool (Figure 3).

The strain rate is one of the most important parameters with regard to continual plasticity deformation and quality of finished part. In this investigation the transfer radius has a value 1mm which decisively influences the field of strain rate (Figure 4) with values from 1.98s-1 (node 575) to 34.14s-1 at the top the die of radius.

The high change of the zz stress tensor component in the meridian cross section, from – 223 MPa to 28 MPa indicates a noncontinual stress distributions near the transfer die radius (Figure 5). The von Mises equivalent stress distribution in the materials structure, from $2.96 \cdot 10^7$ MPa to $67 \cdot 10^7$ MPa near the transfer radius, describes aluminium loading during the process. With three characteristic values node values of the Von Mises stresses ($53.4 \cdot 10^7$ MPa, $55.3 \cdot 10^7$ MPa, $52.8 \cdot 10^7$ MPa) stress conditions in the forming zone can be explained.

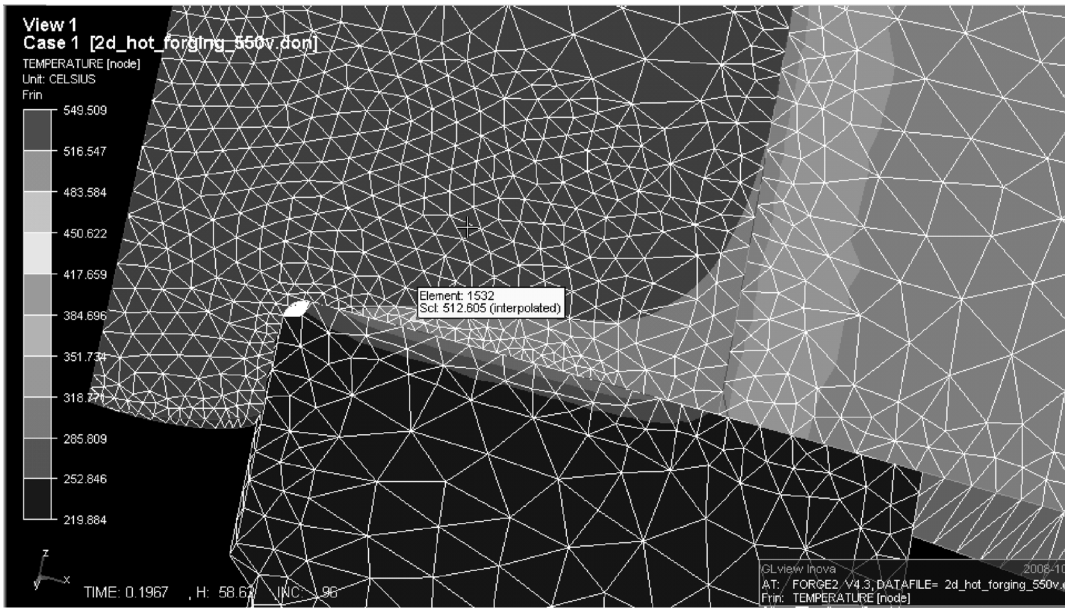


Figure 3. The mesh of tetrahedral finite element in the area of plasticity deformation, temperature field in meridian cross section of aluminium, die and container, problem with waving surface of finished part

Slika 3. Mreža tetraedarskih konačnih elemenata u oblasti plastične deformacije, temperaturno polje u meridijanskom presjeku aluminijuma, matrice i kontejnera, problem sa valnim površinama gotovog dijela

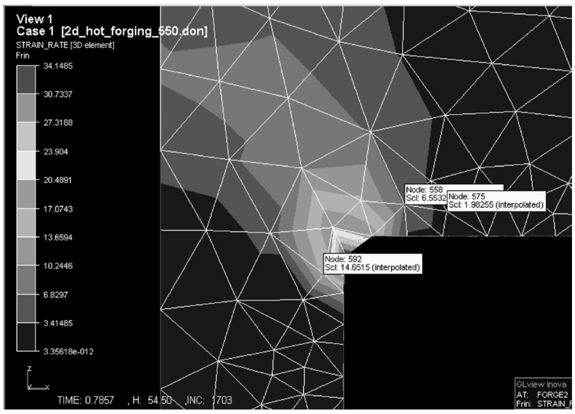


Figure 4. Field of strain rate near the radius of tool

Slika 4. Polje brzina deformacije u blizini radijusa alata

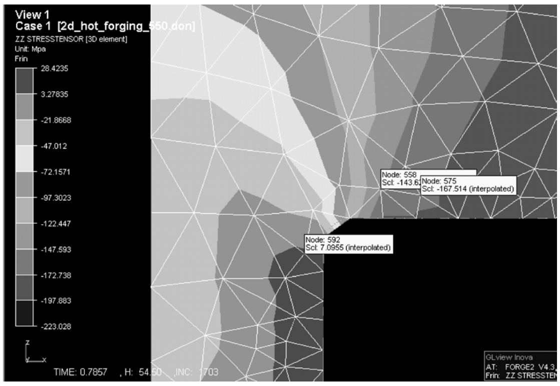


Figure 5. Distribution zz stress tensor

Slika 5. Raspored zz komponente tenzora napona

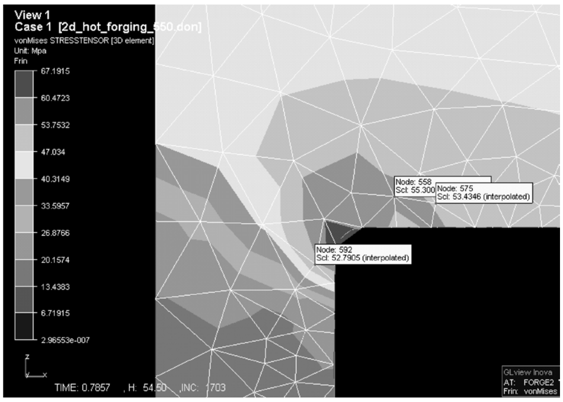
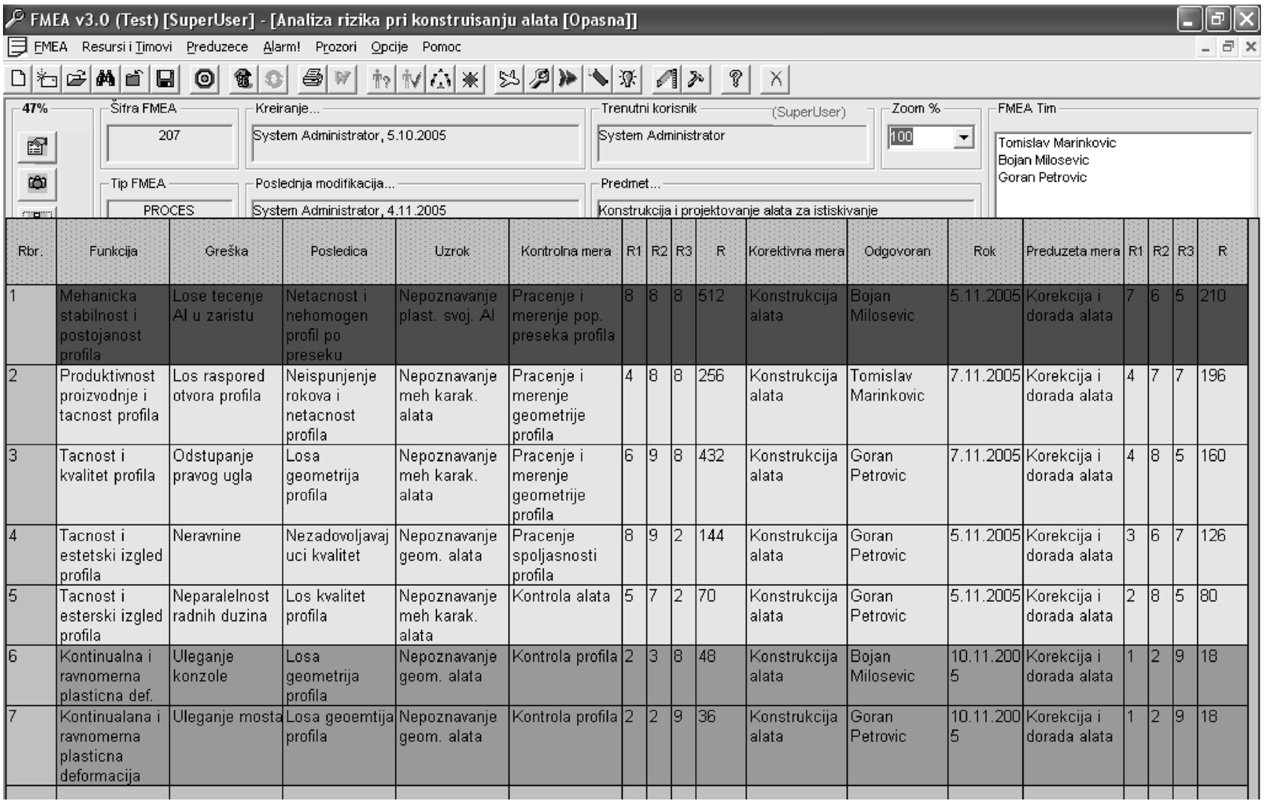


Figure 6. Distribution von Mises stress

Slika 6. Raspored von Misesovih napona

Very frequently the complex conceived requirements are imposed on the extrusion process, in the form of structural designs which surpass the tools capability to adaptation of aluminum and its alloys in those methods. Attempts to realize such designs result in later failures of the most important tool parts which cannot be solved (Figure 1). There are certain construct rules and limitations, based on previous knowledge and experience, which must be observed when designing new structural forms. By accomplishing the set conditions and criteria technology of plasticity, there is a high probability that the structural errors in the beginning can be avoided and these conditions and criteria are given in the data base of FMEA analysis, with description and physical parameters of the process (Figure 7). 3D and 2D modeling and the possibility to simulate nonlinear plasticity deformation and filling of tool cavity are nowadays the proper methods to employ to significantly reduce such errors [2-3].

An illustration of such failures will be an example that can be used to represent a great problem in production aluminium constructions by extrusion technology of half hollow elements. The production of the required



Rbr.	Funkcija	Greška	Posledica	Uzrok	Kontrolna mera	R1	R2	R3	R	Korektivna mera	Odgovoran	Rok	Preduzeta mera	R1	R2	R3	R
1	Mehanicka stabilnost i postojanost profila	Lose tecenje Al u zaristu	Netacnost i nehomogen profil po preseku	Nepoznavanje plast. svoj. Al	Pracenje i merenje pop. preseka profila	8	8	8	512	Konstrukcija alata	Bojan Milosevic	5.11.2005	Korekcija i dorada alata	7	6	5	210
2	Produktivnost proizvodnje i tacnost profila	Los raspored otvora profila	Neispunjenje rokova i netacnost profila	Nepoznavanje meh karak. alata	Pracenje i merenje geometrije profila	4	8	8	256	Konstrukcija alata	Tomislav Marinkovic	7.11.2005	Korekcija i dorada alata	4	7	7	196
3	Tacnost i kvalitet profila	Odstupanje pravog ugla	Losa geometrija profila	Nepoznavanje meh karak. alata	Pracenje i merenje geometrije profila	6	9	8	432	Konstrukcija alata	Goran Petrovic	7.11.2005	Korekcija i dorada alata	4	8	5	160
4	Tacnost i estetski izgled profila	Neravnine	Nezadovoljavaj uci kvalitet	Nepoznavanje geom. alata	Pracenje spoljasnosti profila	8	9	2	144	Konstrukcija alata	Goran Petrovic	5.11.2005	Korekcija i dorada alata	3	6	7	126
5	Tacnost i esterski izgled profila	Neparalelnost radnih duzina	Los kvalitet profila	Nepoznavanje meh karak. alata	Kontrola alata	5	7	2	70	Konstrukcija alata	Goran Petrovic	5.11.2005	Korekcija i dorada alata	2	8	5	80
6	Kontinualna i ravnomerna plasticna def.	Uleganje konzole	Losa geometrija profila	Nepoznavanje geom. alata	Kontrola profila	2	3	8	48	Konstrukcija alata	Bojan Milosevic	10.11.2005	Korekcija i dorada alata	1	2	9	18
7	Kontinualana i ravnomerna plasticna deformacija	Uleganje mosta	Losa geoemtija profila	Nepoznavanje geom. alata	Kontrola profila	2	2	9	36	Konstrukcija alata	Goran Petrovic	10.11.2005	Korekcija i dorada alata	1	2	9	18

Figure 7. Data base of risk analysis at design tool of extrusion (FMEA, ©CIM College®)

Slika 7. Baza podataka analize rizika pri projektiranju alata za istiskivanje

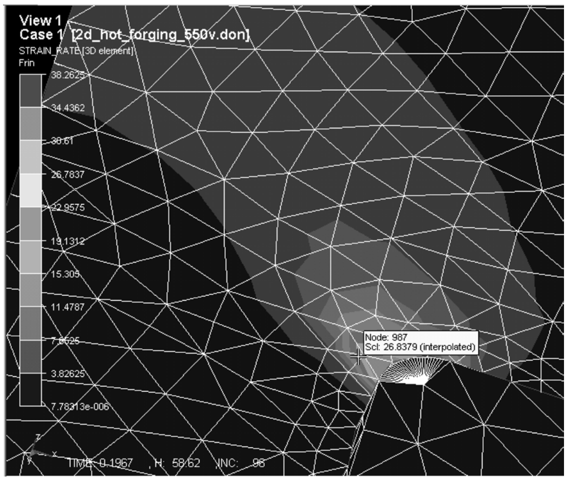


Figure 8. The mesh of tetrahedral finite element in the area of plasticity deformation, strain rate distribution near transfer radius, problem with waving surface of finished part

Slika 8. Mreža tetraedarskih konačnih elemenata u oblasti plastične deformacije, raspored brzina deformacije u blizini prijelaznog radijusa, problem sa valnom površinom gotovog dijela

elements called for the design and making of a tool matrix (Figure 1) with the appropriate cavity which exhibited its deficiencies only after it was mounted on the horizontal hydraulic press (nominal force 25000 kN). A simulation of a non-linear FEM model in the characteristic cross-sections of the tool, (Figure 8) indicated steady state of plasticity deformation, as entry into the orifice channel of tool and regular filling of the tool cavity along the working length which formed the thickness of the wall of aluminium construction.

Despite the attempts to correct the working lengths and to increase the quality of sliding surfaces of tool (polishing) on the already finished matrix, it was evident that the problem had occurred earlier, in the aluminium elements design process (Figure 1). The requirement was that the joint of two parts of the elements should be produced via a rectangular transfer rib (Figure 1) resulting in an increased length of cantilever too (≈ 80mm), which under working pressure of the extrusion process imposed high elastic deformation of tools, i.e. the cantilever part of the tool started to periodically move backwards and forwards in the direction of extrusion, which resulted in the characteristic waving surface on the finished part (Figure 9) [6, 9-10].

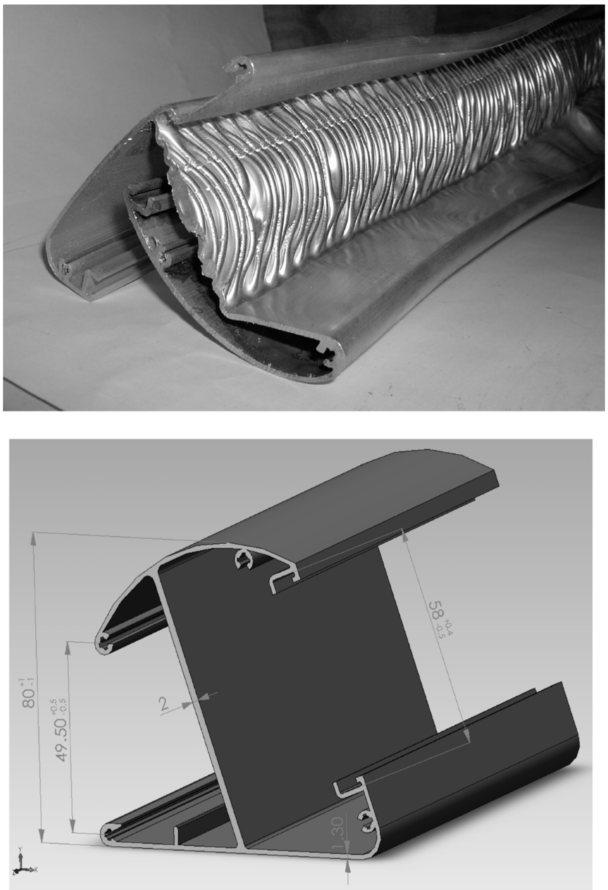


Figura 9. Waving surface of finished part and new solution for constructions

Slika 9. Valna površina gotovog dijela i novo konstruktivno rješenje

Attempts to correct this failure did not lead to succes; thus a new design of the finished parts was made with convention of customer. A second solution had the same position of characteristic connection points for which a new tool, which did not exhibit these deficiencies (thickness of connecting rib is 2 mm, length of cantilever ≈50 mm), was made (Figure 9) [15].

Such individual design solution becomes valuable by being entered into the data base of FMEA (Figure 7. row 7), and by working on the failure until improvement is accomplished, or until it is completely eliminated in hierarchy of construction (Figure 10).

4. Risk analysis and application of FMEA

The said elements are unified and connected into a created FMEA which processes a certain mega process or a process which is the object of the analysis (Figure 7). FMEA itself and its recordings indicate the difficulty and characteristics of the problem processed. Numerous tools used in creating FMEA analysis help team members and management of the company in correcting perceived errors. The essence of the analysis is an assessment and evaluation of the problem prior to and after the correction carried out (Figure 7). Without an assessment and evaluation system, the real effects and results of the analysis would not be achieved [11, 13, 18].

Numerical evaluation of the mentioned errors is assessed by the probability of their occurrence, the so -called risk factor R1 from 1 (improbable) to 10 (very probable). For each cause of the error, the significance of the consequences of its occurrence for a customer is assessed, which is a risk factor R2. For this the values from 1 (no consequences) to 10 (grave consequences) are applied. The term – customer, which was used comprises the end user of product, who will in any of the ways,

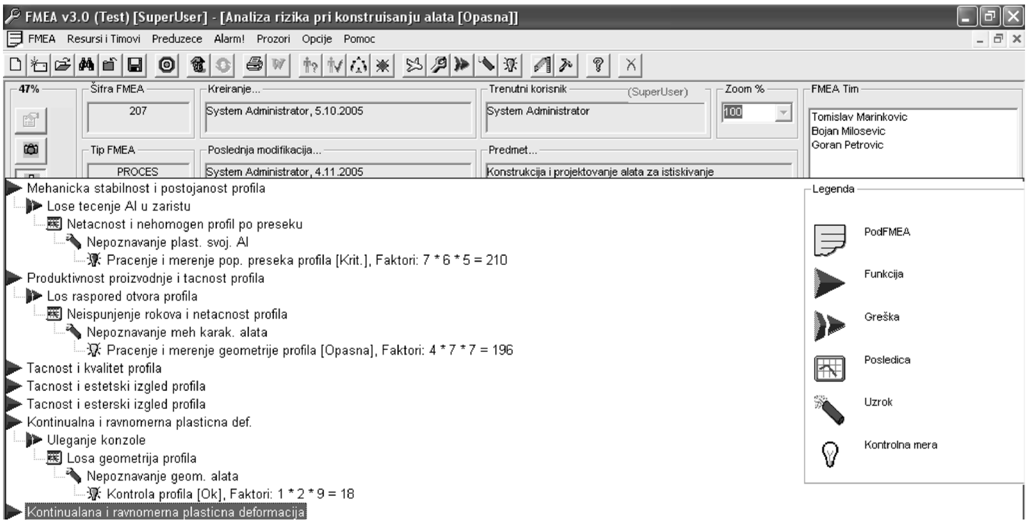


Figure 10. FMEA tool design, display of failure hierarchy (FMEA, ©CIM College®)

Slika 10. FMEA projektovanja alata, hijerarhijski prikaz gresaka (FMEA ©CIM College®)

be directly dealing with the extrusion process errors. The necessary factor takes into account the probability of detecting an error before it reaches the end user, the so-called risk factor R3 in the range between 1 (very probable detection) to 10 (improbable detection).

The production of these three factors, in the range between 1 and 1000 is called the priority risk value, and indicates the possibility that there might not even be any risk, or that the risk is very high. Ranking by priority value of risk and removing all errors which make up most part of the total costs, the process gains a potential to improve and apply appropriate measures. Such intensive work requires a lot of team work in the framework of the company, where with the application of software significant results can be achieved in business as a whole (Figure 4).

5. Conclusion

When the issue is considered comprehensively, it appears that its essence is not the geometrical models, but the solution which, for the given deformation conditions, produces the satisfactory product as an output. When that task is observed in this way, then the experience and knowledge of these issues which is accumulated over the course of years provide an answer to the problem. Now, with the aid of tools such as FMEA a right and best solution can be sought and found. Even those problems which occurred only once, which are widely discussed, but are basically unexplained will be available to a designer in the data basis. With such an approach, a company management systematizes its intellectual potential and technological capital, which is a decisive asset in a contemporary market.

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