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RISK ASSESSMENT IN INJECTION MOLDING PROCESS

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ABSTRACT

Failure modes and effects analysis is one of the most important methods for determining reliability of the whole production system. If this analysis is implemented in the early stage of a process development, many problems and part errors can be reduced. This is essential nowadays, since high competitive markets force manufacturers to produce high quality products as cheap as possible.
In this paper FMEA was performed in case of injection molding process for manufacturing pipe fittings Ø75/45^o and Ø75/90^o, using results obtained from both numerical simulation (MOLDEX3D) and the experiment.
Key words: FMEA, FEM, injection molding, pipe fittings

1. INTRODUCTION

In order to realize an injection molding process successfully and to ensure robust design of the process, it is essential to implement Failure Modes and Effects Analysis (FMEA). FMEA is a systematic, team-oriented, and dynamic method based upon a multidisciplinary approach by which potential failures of both product or process design, manufacturing and product service can be identified, analyzed and documented [1, 2]. It can be said that the main purpose of this analysis is error and problem prevention in the process development, or their reduction if in case that problem is already known and unavoidable. In addition, risk assessment using FMEA may provides the answer associate with confirmation or rejection of part and process design solutions [3]. FMEA method is based upon team work in which every team member has the possibility to record its own remarks and conclusions.
FMEA method has undoubtable benefits for the entire production process. However, in order for it to be economically applicable, one must keep in mind that the costs of FMEA method have to be several times lower that the costs of potential errors that it prevails.

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This paper analysis the errors, their causes and effects by FMEA and introduces the steps for their correction in case of injection molding for manufacturing pipe fittings Ø75/45^o and Ø75/90^o. Numerical simulation based on Finite Element Method (FEM) was performed for the early identification of the process design errors. Based on obtained results some corrections in mold and process design have been made.

2. FEM ANALYSIS

In the design procedure of an injection molding process, it is necessary to take into consideration all relevant process parameters. Numerical simulation and FEM are powerful tool that enables simultaneous analysis of many process variables and different design solutions. Results of this this is an optimized process. Furthermore, FEM model provides a virtual perception of the real process that could help designers to reduce process uncertainness and eliminate most of errors that occur in injection molding cycle at early stage of the process development, i.e. to avoid "trial and error" procedure. Here, FEM based software package Moldex3D [4] was employed for simulation of investigated injection molding process in which pipe fittings Ø75/45^o and Ø75/90^o are produced using the mold with two asymmetric cavities [5]. Due to asymmetric cavities and the fact that main flow divides into two sub-streams within the both cavities this process is technical demanding and filling problems and different failures of parts may occur if runner system is not designed correctly.

Most common defect and errors in injection molding are: welding lines, short shot (Incomplete mold filling), sink ratings, air traps, flash, lamination etc. Welding line is the line with sharp angle formed by two different melting fronts during the mold cavity filling. It directly reduces the strength of the finished product and causes the appearance of visual imperfections and defects, which may have a decisive influence on the quality of the finished part. Region in which welding lines may occur as well as other types of errors (flow ratings, hesitations and material degradation) can be accurately predicted if both progress and temperature of the melt front are known. For example, if the melt front temperature near the potential locations of the weld lines is low, the weld lines will be more noticeable.

Fig. 1 shows melt flow within both cavities and current position of the molten front at different moments during filling stage. It can be seen that melt flow is partially unbalanced which indicate that there is a probability of welding lines occurrence. This is emphasized in case of fitting Ø75/45^o. Graphical presentation of the analysis of potential places of welding lines occurrence at the end of filling process is given in Fig.2.

In most cases, it is very difficult to avoid welding lines. An alternative solution is to locate (by proper design of mold and runner system) the welding lines at places where the strength of the part or ideal smooth surface is not essential. During the design phase, FEM analysis offers the possibility, in order to minimize the poor visual effect and to enhance the strength of the welding line, the following actions may be taken during the design phase: mold or melt front temperature increase, change of gate(s) location, change of the wall thickness, change of the type of the runner system, reduction of runner's diameter (it increases the effect of melt heating due to friction) etc..

In the first design solution of the runner system welding lines are formed at the most unfavorable place – area of the inner grooves (for sealing ring) formed by hydraulically driven side mandrels. Since material of this area is subjected to elastic deformation when side mandrels are pull out and it is desirable to avoid welding lines here. It was done in the next iteration. By changing the gates location more uniform distribution of the melt front temperature was obtained. Therefore, the presentence of weld lines and local weakness of the molded parts are significantly reduced.

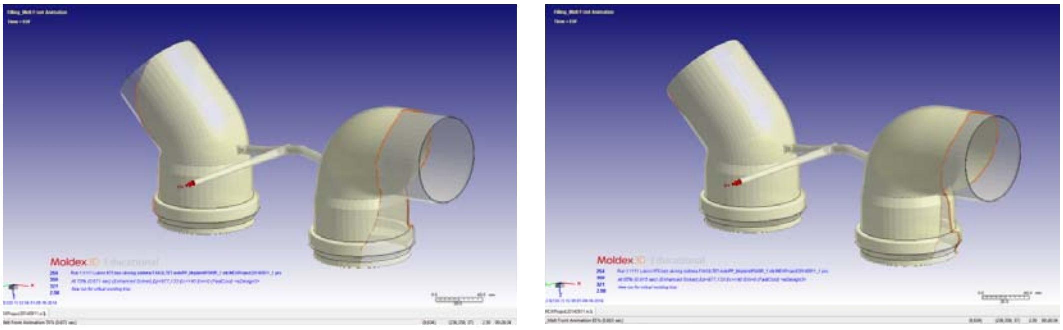

Fig.1 *- Position of the melt fronts for diffrent filling stages (70% - left and 85% - right)*

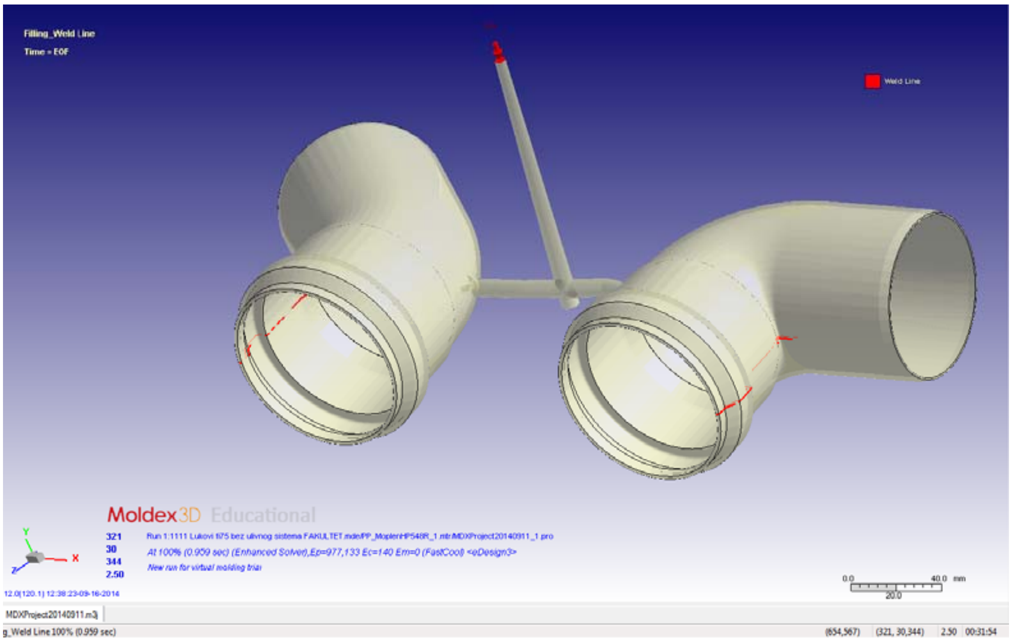

Fig.2 *- Welding lines predicted by MOLDEX3D*

3. FMEA OF THE INVESTIGATED PROCESS

In order to gain full understanding of a complex process such as injection molding FMEA should be carried out dynamically. This means that the current state of the process is not recorded as a static and unchangeable set of data but the data and estimates are permanently updated and calculated periodically. The entire work with FMEA applications consists of two parallel but entirely separate processes: classification and quantification of identified risk or errors. The idea is to determine whether implemented FMEA is beyond critical line, dangerous, alright, or if any of its containing data and information are not processed.

When choosing the level of FMEA, one should always go from the general to the individual. Firstly, the whole mega FMEA process is considered, followed by FMEA analysis of complete single processes and then, at the end certain, individual activities are considered. In such a division, FMEA gains on accuracy and precision, and this takes into consideration each individual process parameter.
The biggest contribution of FMEA method can be obtained only by using accurate process steps and complete process definition in order to avoid neglecting important process segments. FMEA applied for investigated injection molding process consists of the following tasks:

- Determining the function of the pipe fittings Ø75/45^o and Ø75/90^o
- Identification of all possible errors in the pipe fittings production (Ø75/45^o and Ø75/90^o)
- Determination of the causes for all error types in the pipe fittings production (Ø75/45^o and Ø75/90^o)
- Defining the outcome or the effect of all observed errors in the pipe fittings production (Ø75/45^o and Ø75/90^o)
- Determination of risk priority number (RPN) and the possibility of error detection (D)
- Defining the most suitable corrective measures for reducing or complete eliminating the risk
- Monitoring and keeping track of corrective and preventively taken measures.

Every possible error in production of pipe fittings Ø75/45^o and Ø75/90^o are evaluated with ratings 1 - 10, by using 3 basic criteria:

- Severity of the error (S)
- Frequency of error occurrence (O)
- Possibility of error detection (D)

By multiplying these criteria, a risk priority value can be calculated:

$$S \times O \times D = RPN \qquad (1)$$

Every error is ranked based upon RPN number in order to evaluate its importance by means of the difficulty to eliminate it and the financial effect on the injection process. Errors with RPN numbers higher than 100 are considered critical. Aim of this kind of analysis is to put the process risk in the desired control. If that is not possible, this analysis at least enables accurate identification of errors and prediction of critical process parameters. FMEA methods are usually periodically evaluated.
One of the most common causes for errors in injection molding is human factor. Because of that, corrective measures, which are associated to all participants in production process, are included. Connecting the behavior of human errors with FMEA method is one of the possible ways to create a more comprehensive analysis and by that to appoint measure that will improve the quality of the production process [6].
Few typical errors that have occurred during injection molding of the Ø75/45^o and Ø75/90^o pipe fittings are depicted in Figs. 3-8, as Table 1 presents results of FMEA analysis of the errors before and after correction of mold and process design. Based upon predetermined probability of error occurrence in relation to possible causes, a probability, severity and elimination possibility of the error was determined.

Fig.3 *- Overflow error for fitting 75/45º and short shot error for fitting 75/90º due to unbalanced runner system and low clamping force (760kN)*

Fig 4. *- Short shot error for fitting 75/90º due to unbalanced runner system and low injection pressure*

Fig.5 *- Short shot error due to dirt in the nozzle*

Fig.6 *- Overflow error due to high injection pressure*

Fig.7 *- Short shot errors due to insufficiently heated tool*

Fig.8 *– Noticeable welding lines*

Limiting values of RPN in manufacturing pipe fittings Ø75/45^o and Ø75/90^o are set as following:

1 – 5: acceptable, solved by operator
6 – 30: acceptable, solved by operator with higher attention
31 – 150: undesirable, suggested corrections require measures from FMEA which are solved by operator under process designer supervision
150 and above: unacceptable, the entire team is engaged, with the possibility of consultation with external experts, machine manufacturer or material supplier.

S – severity of the error in financial aspect (1 – low costs, 10 – high costs)
O – error frequency (1 – rarely, 10 – often)
D – error detection (1 – easy, 10 – hard)

Table 1 *- FMEA analysis in production environment*

<table>
<tr><th rowspan="2">ERROR</th><th rowspan="2">ERROR CAUSE</th><th colspan="3">ERROR RATING</th><th rowspan="2">RPN

O x S x D</th><th rowspan="2">CORRECTIVE ACTION</th><th rowspan="2">RESPONSIBILITY</th></tr>
<tr><th>S</th><th>O</th><th>D</th></tr>
<tr><td rowspan="3">Short shot

Cavity is insufficiently filled due to low mass flow – the final part is unusable

Fig. 4</td><td rowspan="3">Low injection flow</td><td>10</td><td>3</td><td>1</td><td>30</td><td rowspan="3">• Increase injection pressure
• Increase molt temperature (reduce viscosity)
• Increase injection velocity
• Material with higher MR. (flow index)</td><td rowspan="3">• Operator
• Operator
• Operator
• Process designer</td></tr>
<tr><td colspan="4">Error rating after FMEA corrective actions</td></tr>
<tr><td>10</td><td>2</td><td>1</td><td>20</td></tr>
<tr><td rowspan="3">Short shot

Cavity is insufficiently filled due to low starting mass– the final part is unusable</td><td rowspan="3">Insufficient mass</td><td>10</td><td>5</td><td>2</td><td>100</td><td rowspan="3">• Set adequate amount of the resin mass
• Use more uniform granulation of recycled material and better mixing with original material</td><td rowspan="3">• Operator
• Recycling (better resin preparation)</td></tr>
<tr><td colspan="4">Error rating after FMEA corrective actions</td></tr>
<tr><td>10</td><td>3</td><td>1</td><td>30</td></tr>
<tr><td rowspan="3">Short shot

Cavity is insufficiently filled due to low mass flow caused by impurities in machine nozzle – the final part is unusable

Fig. 5</td><td rowspan="3">Dirt in the nozzle</td><td>10</td><td>2</td><td>2</td><td>40</td><td rowspan="3">• Clean the nozzle
• Clean the recycled material
• Magnet for dirt collecting</td><td rowspan="3">• Operator
• Recycling (better resin preparation)
• Operator</td></tr>
<tr><td colspan="4">Error rating after FMEA corrective actions</td></tr>
<tr><td>10</td><td>1</td><td>2</td><td>20</td></tr>
</table>

Table 1 *- Continue*

ERROR	ERROR CAUSE	ERROR RATING S	ERROR RATING O	ERROR RATING D	RPN O x S x D	CORRECTIVE ACTION	RESPONSIBILITY
Short shot Cavity is insufficiently filled Fig. 7	Cold tool	10	1	1	10	• Heat up the tool	• Operator
		Error rating after FMEA corrective actions					
		10	**1**	**1**	**10**		
Overflow Cavity is overfilled – the final part is usable only after material removal Fig. 6	• Oversized shot • Injection pressure too high	1	1	2	2	• Adjust the short size • Reduce injection pressure	• Operator • Operator
		Error rating after FMEA corrective actions					
		1	**1**	**2**	**2**		
Overflow Cavity is overfilled – the final part is usable only after material removal Fig. 6	• Force of hydraulic cylinder(s) driving side mandrels too low	5	2	1	10	• Use the cylinder with higher piston diameter (note the cylinder number and write down its number in technical papers	• Operator
		Error rating after FMEA corrective actions					
	• Short stoke of side pins	**5**	**1**	**1**	**5**	• Place an adequate connector - reducer to the cylinder of guiding system of the side mandrels	• Mold designer and operator

Table 1 *- Continue*

ERROR	ERROR CAUSE	ERROR RATING			RPN O x S x D	CORRECTIVE ACTION	RESPONSIBILITY
		S	**O**	**D**			
Short shot and overflow One cavity is overfilled and another is filled insufficiently - the final part from overfilled cavity is usable only after material removal as the second one is not usable Fig. 3	• The clamp force too low for the given injection pressure • Unbalanced runner system	5	7	2	70	• Increase the clamping force • Reduce the injection pressure • Better balance of runner system • Change of the gates location	• Operator • Operator • Mold designer • Mold designer
		Error rating after FMEA corrective actions					
		5	**5**	**2**	**50**		
Part cracks The parts crack along the welding lines when pulling out mandrels Fig. 8	• Local material weakness due to welding line	10	5	2	100	• Increase mold temperature • Increase melt temperature • Reduce the amount of recycled material • Shorten cooling time • Change of the gates location	• Operator • Operator • Operator • Operator • Mold designer
		Error rating after FMEA corrective actions					
		10	**3**	**1**	**30**		
Burned part Part burning occurs at locations with trapped air – the part is functionally usable, but with severe esthetic imperfections	• Trapped air	5	1	1	5	• Change of the gates location • Remove the trapped air • Correction in the part design (change the wall thickness if possible)	• Mold designer • Mold designer • Mold designer
		Error rating after FMEA corrective actions					
		3	**1**	**1**	**3**		

After the FMEA analysis and several months later of applying the corrective measures, noticeable improvement of the injection molding process have been achieved. Those results are presented in the Table 1 (bolded results) and experimentally verified (Fig.9). As it can be seen from table 1, after performing corrections there is no error with RPN higher than 150 which is considered as limit of acceptability. It is important to point out that RPN level for the most detected errors is reduced only by better cleaning of the nozzle and by simple correction in the resin content. As an example of this is the short shot error due to insufficient injected mass – occurrence of the error is minimized by better mixing of the resin (better homogenization) and using recycled material with finer granulation. Also, the value of the RPN is reduced to a tolerable level (from 40 to 20) with a more consistent implementation of the prescribed measures from the FMEA for the short-injection error caused by impurities in the nozzle. The best results (RPN reduced from 100 to30) were accomplished in reducing the crack error caused by welding lines when pulling out side mandrels. However, taking into account that given value of RPN = 30 is a limit value which can easily be exceeded, significant mold design involvement is required i.e., change in the gates locations according results of Fem analysis. Result of this would be RPN reduction into acceptable risk level (RPN from 1 to 5), and consequently significant improvement of the process economy.

Fig.9 *- Pipe fittings injected after FMEA correction actions (no visible errors present)*

4. CONCLUSION

Common problem of a number companies they are faced up recently is leaving of “key” people or experts with relevant knowledge, skills, competences, and huge experience. Nowadays, when investing in researches and development is the privilege only for the most powerful companies such people are highly wanted. Problem of missing experts may be overcome if company posses FMEA documentation since it contains set of recorded expert knowledge collected during many years such as data in table 1. Significance and benefit of this documented knowledge lies in the fact it is available to everyone included in the process design chain and can be used as guideline for design of similar processes.

In this paper, some of FMEA capabilities are demonstrated in case of injection molding process for manufacturing pipe fittings. In that sense, potential failures and their causes are fully identified firstly using the finding from FEM simulation and experiment as in next step corrective actions based upon this analysis were defined. After few months implementing the suggested corrections obtained results were more than evident. The process stability was increased, most of part’s defects and errors are reduce to minimum especially cracks caused by part weakness due to welding lines, quality and accuracy improvement of final parts is achieved, productivity growth is present, etc.

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PROCENA RIZIKA U PROCESU INJEKCIONOG BRIZGA

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Abstract

Analiza procene rizika predstavlja jednu od najvažnijih metoda za utvrđivanje pouzdanosti celog proizvodnog sistema. Ako se ova analiza sprovodi još u početnim fazama razvoja proizvoda i tehnološkog postupka njegove izrade mnoge neželjene pojave i greške na radnim predmetima mogu se izbeći ili njihovo prisustvo smanjiti. Ovo je danas veoma bitno je velika konkurencija na tržištu presijava proizvodiće da neprekidno podižu kvalitet svojih proizvoda uz što nižu cenu.
U ovom radu analiza procene rizika primenjena je na proces injekcionog brizganja za izradu lučnih elemenata Ø75/45^o i Ø75/90^o. kanalizacione instalacije, korišćenjem rezultata dobijenih putem numeričkih simulacija i eksperimentalno.
Ključne reči: analiza procene rizika, metoda konačnih elemenata, injekciono brizganje, lučni element (fiting)