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USING THE PARETO DIAGRAM AND FMEA (FAILURE MODE AND EFFECTS ANALYSIS) TO IDENTIFY KEY DEFECTS IN A PRODUCT

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Abstract:
The article presents the results of studies conducted in a company manufacturing aluminium forgings for the automotive industry. The aim of the research was to identify the defects which form during the production process as well as the locations and causes of their occurrence. Selected quality management tools were used in the process. Based on the FMEA and the costs generated by the identified defects, a hierarchy of them was created for the company along with a proposal of improvements in case of the most significant ones in order to reduce their number and increase the detection efficiency.

Key words: *quality, FMEA, Pareto, defect, management, production engineering, forging*

INTRODUCTION

The situation of the automotive branch, as reported by various sources, is getting worse with each passing year [1]. A decrease in the number of produced cars forces companies specialising in this field to fight for a good position on the market and customer's trust. That is why, in order to stay on the market, companies which manufacture cars and car parts have to increase the quality of their products by constantly improving the production processes in both the technical and organisational aspects [2]. Every return or detected defect can pose a threat to the existence of the company later on.

Defects of any type have an impact on the quality of the product and, as a result, on the success and way of realising the production objectives. The defects which form at all stages of the production process, unfortunately, cannot be completely eliminated, but we can try to reduce their number to a minimum. It forces the companies to implement all sorts of improvements in a form of: methods, tools and additional monitoring systems, which are aimed to increase the quality of the production cycle as well as the final product. The improvements apply not only to the functioning of machines and devices, but also to the way of managing and organising the production [3].

The process of increasing the quality of the products and improving the production process is arduous, long and requires the involvement of both the managing staff and the machine operators. To successfully reduce the level of product defectiveness, we first need to identify all the defects that can be formed in the production process as well as the places where they are generated. The next stage should be a thorough and objective analysis of the causes of their occurrence, which will, in turn, result in properly formulated improvement measures. Those measures should be, first of all, focused on reducing the number of defects being formed, but also increasing the detection efficiency [4]. Countless tools and methods of quality management can be helpful in this process [5]. Three of them were used in the description provided in this article: the Pareto-Lorenz diagram, the Ishikawa diagram and the FMEA.

The analysis of product defectiveness was conducted in a company manufacturing aluminium forgings for the automotive industry.

THE PARETO ANALYSIS

Conducting an analysis requires that we identify what kind of defects the company is dealing with and what the scale of the problem is in the studied period of time. The Pareto-Lorenz analysis is a very useful tool for this purpose, presenting visually and in a clear way the results of the studies.

The most common identified defects in the examined factory are:

- damage to the surface of the forging – the surface is considered damaged the moment an employee notices a flaw, a deep crack or a discolouration visible.
- cracks of the forging – occur when there is a visible discontinuity in the material, usually in the form of a chink.
- exceeding the diameter tolerance – identified by checking the dimensions of a given item with a calliper and comparing it with the established requirements.
- dents – appear as a result of the material collapsing inwards due to a hit or unsafe practices and during the transportation, storing and packaging of the material.
- improper hardness – identified through laboratory tests using a hardness tester.
- fractures – characterised by a complete discontinuity of the material.

– skews – identifying them consists in measuring the degree of deflection of the forging's surface against a benchmark.

In the Pareto analysis were used the number of defects occurring and their unit cost, which allowed determining the total costs the company has to bear due to the occurrence of these defects. The costs include: the cost of removing the defect, the cost of scraping a faulty element and potential additional costs, e.g. the cost of transporting the faulty elements to the customer, etc. [6].

Based on the data, a Pareto-Lorenz diagram, presented in Figure 1, has been drawn. The cost incurred by the company due to the defects forming as well as the cumulative percentage of the cost of these defects have been marked on the ordinate axis.

The diagram indicates that the most significant defects in terms of costs to the company are (in descending order):

1. Exceeding the dimension tolerance,
2. Improper hardness,
3. Cracks of the forging,
4. Damage to the surface of the forging,
5. Fractures,
6. Skews,
7. Dents.

In the next stage, the defects were divided into 3 groups, according to the ABC principle [7]:

– group A – defects which generated 80% of the overall costs; the cumulative cost is less or equal to 80% of the cumulative costs.
– group B – defects which, together with those from group A, generated 95% of the overall costs; the cumulative cost is less or equal to 95%.
– group C – defects whose combined and cumulative costs amount to 5% of the whole, and have not been assigned to groups A or B.

The results of the Pareto analysis and ABC are presented in Table 1.

According to the ABC principle, first 3 defects, which generate 72% of all costs, have been placed in group A. Removing or reducing the number of occurrences of those defects should be of topmost priority to the company. The result of the implemented changes should be a significant reduction of costs the company bears due to faulty products. Two defects were placed in groups B and C.

Minimising the production costs is only one of the elements of the production process continuous improvement. Other important aspects of defect formation include detection efficiency as well as defect's significance and probability of occurrence. Not taking these aspects into account puts the company at risk of losing its reputation among the customers, which can result in a decrease in the number of purchase orders despite the constant reduction in production costs. Apart from the price, customers also value the quality of the product and, having accepted it, its stability. To look closer into the significance of each defect, the first part of the FMEA has to be carried out.

THE FMEA

Analysing the potential causes and effects of defects requires a larger amount of resources than using simple tools. The participation of experts who know the production process and the manufactured product is necessary in its preparation. Using the analysis, we can measurably identify the causes of defect formation and evaluate three most important parameters of the defect:

– the significance of the defect's effects,
– the probability of the defect occurrence,
– the detectability of the defect.

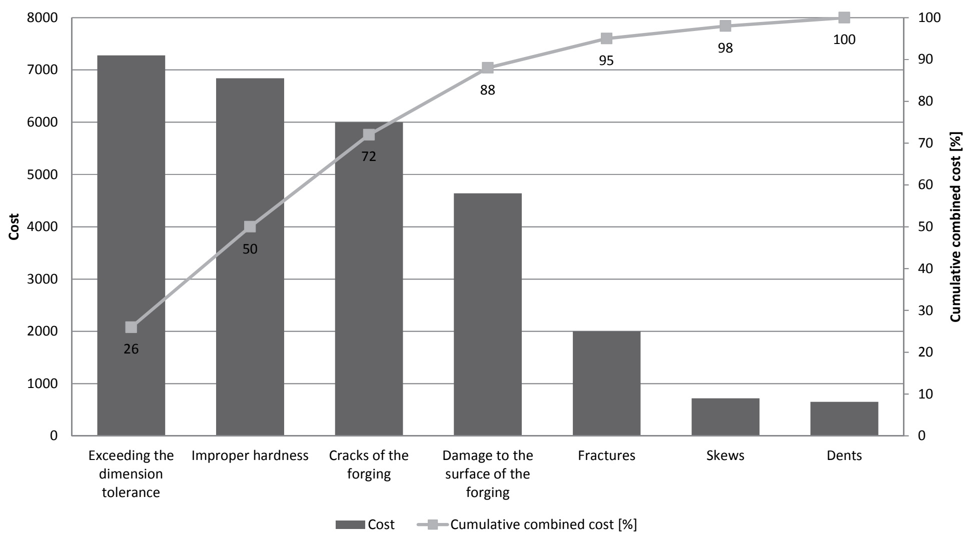

Fig. 1 The Pareto-Lorenz diagram of the cost of defects

Table 1
Cost of the defects along with an ABC classification

Name	Cost	Combined cost [%]	Cumulative combined cost [%]	Group
Exceeding the dimension tolerance	7280	26	26	A
Improper hardness	6840	24	50	A
Cracks of the forging	6000	21	72	A
Damage to the surface of the forging	4640	16	88	B
Fractures	2000	7	95	B
Skews	720	3	98	C
Dents	650	2	100	C

Table 2
Coefficients for the FMEA

Name of the coefficient	Value	Characteristics	Description
R significance of the defect's effects	1	none or very low	The defect has no impact on the quality of the product.
	2 – 3	low	The defect is tolerated or its costs are low.
	4 – 6	average	The defect has an impact on the quality of the product, causes minor inconveniences.
	7 – 8	important	The product does not meet the requirements; the costs are high.
	9 - 10	extremely important	The defect threatens safety.
P probability of the defect occurring	1	improbable	We can imagine the defect forming.
	2 – 3	very low	The defect occurs rarely.
	4 – 6	low	The defect occurs occasionally.
	7 – 8	average	The defect recurs periodically.
	9 - 10	high	The defect recurs very often.
N detectability of the defect	1	high	The control measures detect the defect.
	2 – 3	average	High chance of detecting the defect.
	4 – 6	low	Detecting the defect is possible.
	7 – 8	very low	The verification measures will probably not detect the defect.
	9 - 10	improbable	The defect will not be detected by control measures.

By multiplying all of these coefficients, we obtain the Risk Priority Number or RPN, which informs us about the significance of the defect in the production process; it does not, however, tell us about the cost of these defects' occurrence [8]. The coefficients assumed in this analysis have been presented in Table 2.

When proceeding to perform the FMEA, we identified the key causes of defect formation using the Ishikawa diagram. For each of the defects, a separate diagram was created, containing the following potential causes: man, material, machine and method. When creating the Ishikawa diagram, we determined the major reason for the occurrence of respective defects. These causes became the starting point for the FMEA. Next, the coefficients R, P and N as well as the RPN product were calculated for all the identified defects, as presented in Table 3.

The analysis indicates that the defects of highest significance, which affect the final effect substantially, are: No. 1 - damage to the surface of the forging (RPM = 160) and No. 2 – dents (RPM = 140). The defects of lower significance include: improper hardness, fractures, skews (RPM=120). Defects number 3 and 2 are the least significant.

Table 3
FMEA results

No.	Defect	R	P	M	RPM
1	Damage to the surface of the forging	5	8	4	160
2	Cracks of the forging	10	3	1	30
3	Exceeding the dimension tolerance	10	3	2	60
4	Dents	5	4	7	140
5	Improper hardness	8	3	5	120
6	Fractures	10	6	2	120
7	Skews	10	4	3	120

DISCUSSION OF THE RESULTS

When collating the two methods, i.e. the Pareto-Lorenz diagram and the FMEA, we can see that the significance of the defects is not consistent. A comparison of the results obtained by using both these tools has been presented in Table 4.

The defects most important from the process point of view do not correlate with the list of the most costly defects (Tab. 4). The defect which generates the most losses, i.e. exceeding the dimension tolerance, is in the last place on the FMEA list while the defect with the least significance in terms of costs is in the second place in the RPM ranking.

To look holistically at the issue of defects in the company, from both the process and cost points of view, we need to combine the results of the two analyses. This way, the graph shown in Figure 2 has been created.

The graph (Fig. 2.) presents the percentage shares of all defects, for both the Pareto analysis and the FMEA. The same importance (50/50) has been assumed for both results. Depending on the needs, we can, of course, assign a different level of significance to the costs and the RPM.

As can be seen, having combined the results of the two analyses, we obtain an entirely new hierarchy of defects, as illustrated in Table 5.

Improper hardness, damage to the surface of the forging and exceeding the dimension tolerance proved to be the most significant in the broad approach. Less important defects include: cracks, fractures, dents and skews of the forgings.

Table 4
A comparison of the Pareto analysis and the FMEA results

Name of the defect	Ranking according to the FMEA	Ranking according to costs in the Pareto analysis
Damage to the surface of the forging	1	4
Indentations	2	7
Improper hardness	3	2
Fractures	3	5
Skews	3	6
Exceeding the dimension tolerance	6	1
Cracks of the forging	7	3

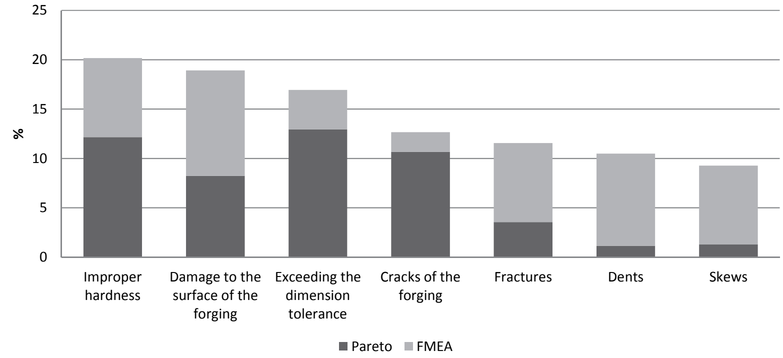

Fig. 2 A comparison of the Pareto analysis and the FMEA results

Table 5
The results of all analyses for the examined defects

Name of the defect	Total ranking	Ranking according to the FMEA	Ranking according to costs in the Pareto analysis
Improper hardness	1	3	2
Damage to the surface of the forging	2	1	4
Exceeding the dimension tolerance	3	6	1
Cracks of the forging	4	7	3
Fractures	5	3	5
Dents	6	2	7
Skews	7	3	6

SUMMARY

The conducted analyses show that improper hardness of the forging is the main problem the company is struggling with and it should be eliminated in the first place. This defect holds a key position in both analyses and, therefore, has been recognised as the most significant one. In order to reduce the number of faulty products, a change to the system of component weighing has been proposed to minimalize the mistakes on the staff's part. The change proposed in order to increase the detectability of this defect is to increase the number of hardness measurements twofold by moving the test station closer to the production line and, in the case of finding a forging which does not meet the hardness requirements, testing the entire batch in a laboratory.

With regard to cracks of the forging, the following preventive measures have been proposed in order to reduce the number of defects occurring:

- increased caution when transporting and storing the forgings,
- equipping the employees with anti-slip gloves,
- modifying the construction of the storehouse racks,
- modifying the forging cooling system,
- automated forging temperature measurement system.

In order to increase the detectability of the defect, we proposed increasing the frequency and accuracy of monitoring by improving the lighting of the test stations and equipping the operators with magnifying glasses.

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