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DEFECT ANALYSIS OF EN AC-435000 ALLOY DIE CASTINGS USING THE PARETO-LORENTZ DIAGRAM

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Purpose: The purpose of this research is to describe the most important defects in die castings made of EN AC-435000 alloy and to present preventive measures and to rank these defects using Pareto-Lorenz analysis.
Design/methodology/approach: The paper provides a comprehensive look at the causes of defects in finished products. During the analysis, Ishikawa and Pareto-Loretnz diagrams were used to get information on what are the main defects in finished products and what steps should be taken to optimize the production process.
Findings: An research was used a typical material applied in the aerospace and automotive industries. The article shows that even small deviations from the accepted technological assumptions, in this case temperature, leading to products that deviate from the accepted quality assumptions.
Practical implications: The article is intended not only for the scientific community, including students, but also for technologists working in industry. It shows the process of identifying the locations and types of damage to finished products and what steps should be taken to avoid them in the future.
Originality/value: Demonstration, difficulties in optimizing the die casting process for EN AC-435000 alloy.

Keywords: Pareto-Lorentz diagram, EN AC-435000 alloy, defect analysis.

Category of the paper: Technical Paper.

1. Introduction

In recent years, research carried out in the automotive and aviation fields has made significant progress. These advances are mainly related to the need to reduce the harmful effects of vehicles on the environment, including by reducing the weight of vehicles or reducing

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emissions of toxic exhaust components (Satyarth, Rohan, Vibhuti, Sangwan, Mahanta, Feroskhan, 2022, pp. 1554-1560). A lot of possible solutions have been developed in this element, including the production of hybrid or electric cars (Asus, Madon, Che Daud, Said, Aglzim, Talib, Ahmad, 2022, p. 032012), downsizing technology in engine construction. Despite this, the abandonment of the use of internal combustion engines, takes time, and that is why manufacturers are focusing on reducing fuel consumption, and thus reducing the weight of vehicles and lower emissions of CO_2, among other things (Alemayeehu, Firew, Nallamothu, Wako, Gopal, 2022, p. e09679). Looking from this side, aluminum alloys are proving to be one of the best solutions to meet both structural and environmental requirements. Modern aluminum alloys, thanks to appropriate modifications, have significant specific mechanical properties and significant corrosion resistance. These unique properties make it possible to use these alloys in many parts of vehicles, from automobile chassis, aircraft structures to components of piston and turbine engines. Aluminum-silicon alloys are widely used in the automotive and aerospace sectors, for example, for the manufacture of pistons (Vamsikrishna, Shruti, Divya Sharma, 2021, pp. 589-597). The primary method of manufacturing automotive pistons from aluminum-silicon alloys is die-casting. This is due to the cost and speed of manufacturing. However, numerous manufacturing defects are revealed during production.

The number and type of defects in die-casting processes are influenced by technological parameters and physicochemical phenomena, which mainly include:

- the molding of the casting, especially compliance with the principles of die casting,
- the profile of the mold, i.e., its shape, position and dimension of the gating system, overflows and vents,
- optimization of process parameters.

In order to get them right, any errors should be detected and corrected during inter-operational inspection. This inspection influences the reduction of the proportion of defects, but does not eliminate them completely. Final testing of castings usually involves checking the castings for correct weight, chemical composition, dimensions, structure and strength properties. When the test results differ from the initial assumptions, it can be claimed that the castings are defective (Saxena, Godara, Chouhan, Saxena, 2021, pp. 1622-1634). The type of casting defects is defined by the Polish standard PN-85/H83105.

In die casting processes, the most characteristic casting defects are porosity, cracks, underfilling, subsurface blistering and adhesion to the mold (Gupta, Kumar, Chandna, Bhushan, 2020, pp. 2429-2443). These defects can be divided into two basic types: raw surface defects, visible to the naked eye, and internal defects (Dhisale, Vasavada, Tewari, 2022, pp. 3189-3196).

2. Aim and scope of the study

The purpose of the research is to describe the most important defects in die castings made of EN AC-435000 alloy and to present preventive measures and to rank these defects using Pareto-Lorenz analysis.

In order to realize the adopted goal, the scope of the study included:

- characterization of typical defects in EN AC-435000 alloy die castings and preventive measures,
- classification of casting defects using the Ishikawa diagram,
- analysis of casting defects using the Pareto-Lorenz method,
- summary and final conclusions.

EN AC-435000 alloy is a popular silumin used for die-casting of engine parts and so-called structural details that form the exterior structure of automobiles. Due to the complexity of the castings, often thin-walled castings, it is an alloy designed for high-pressure casting.

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3. Typical defects in die castings with special emphasis on EN AC-435000 alloy

The main defects arising in die castings we can include:

1. Cold flows (underfills; non-fills; ripples).
2. Sticking.
3. Cracks in castings (hot and mechanical).
4. Mechanical defects (creases, pulls, cracks).
5. Subsurface blisters.
6. Fills.
7. Discoloration.
8. Porosity (gas and shrinkage).
9. Non-metallic inclusions.

The various defects that arise in die castings are presented in Figure 1.

If any of the defects shown occur, the product is marked as defective and requires disposal or additional treatment. Depending on the number of individual defects, appropriate corrective and preventive measures are introduced and must be implemented in the corresponding production or post-production process. As an example, a situation can be given where an increased number of defects in the form of cold flows (underflows, non-welds, folds) has been determined in the production process and the reasons for this can be various, i.e., incorrect (too low or too high) casting temperature or too low casting pressure. In such a case, it will be necessary to verify the temperature measurement system, among other things, by checking whether maintenance (replacement / cleaning) was carried out as planned. Another example is mechanical defects (nicks, cracks, creases), which can arise either in the production process (mold damage) or post-production arising on the casting surface during the trimming process.

It should be remembered that some defects require correction (immediate action) at the appropriate production stage, e.g. underfills, and others require preventive action, e.g. discoloration, where the genesis of the cause is not easy to identify. In the latter case, in the analyzed company, the diagnosis of the origin of the cause is determined by the production manager together with the personnel responsible for the technical condition of the production line.

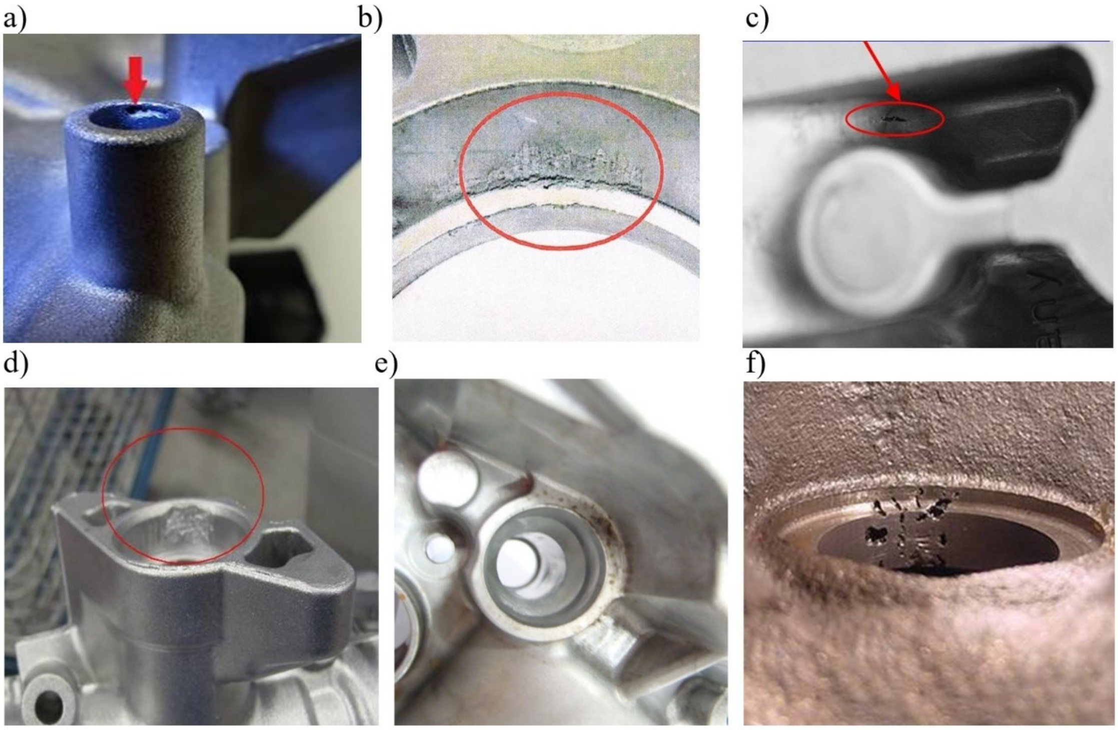

Figure 1. Defects in the workpieces revealed in the production process: a) underfilling, b) sticking, c) cracks, d) breakouts, e) discoloration, f) macroporosity.

4. Classification of casting defects using the Ishikawa diagram

In order to fully illustrate the casting defects that arise in the production process of die castings, an Ishikawa diagram was used. In creating it, due to the specifics of the analyzed process, the typically used groups of causes in the 5M (6M) form were omitted, while the main causes were divided into four basic groups:

a) defects in shape,
b) internal defects,
c) raw surface defects,
d) continuity breaks.

These groups were selected based on a review of the literature in this area and past experience from operating the manufacturing process. Then, to each of the main groups of causes, detailed casting defects were assigned based on past experience and ongoing internal analysis.

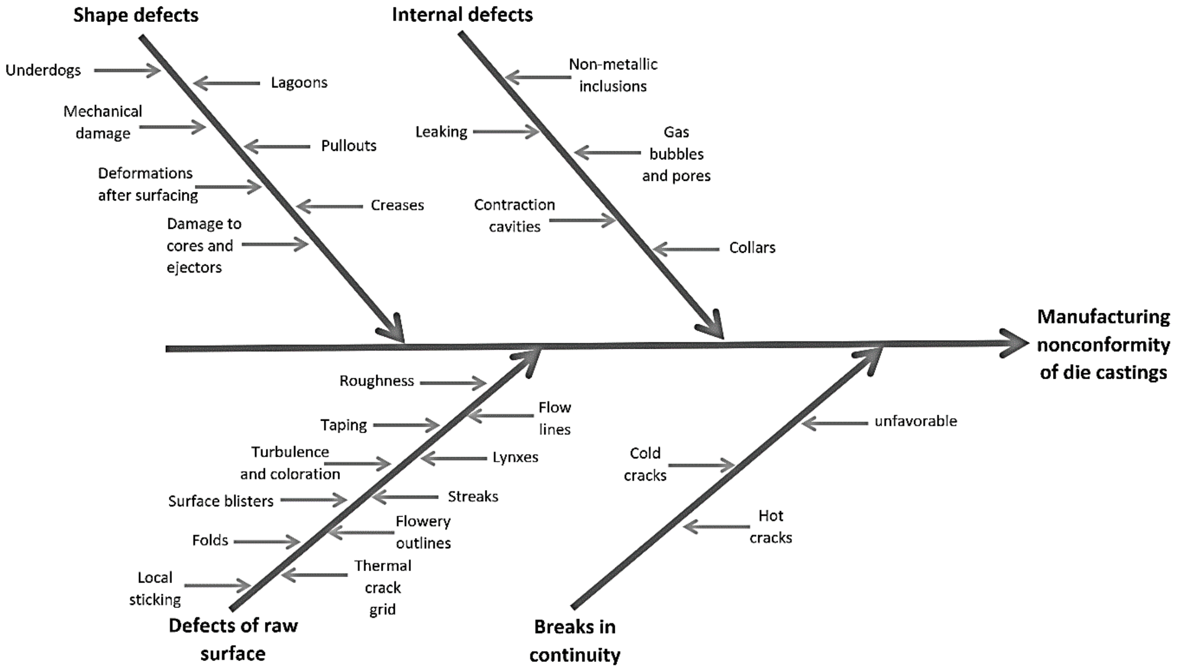

Figure 2. Ishikawa diagram for die casting defects.

Figure 2 shows an Ishikawa diagram depicting the problem of production irregularity associated with manufacturing nonconformity of die castings. In this type of diagram, it is not possible to assess the importance of individual causes, but it is possible, for example, to identify which group the most causes have been classified into. When analyzing the diagram related to the manufacturing process of die castings, it can be seen that the most causes of nonconformity are concentrated in the category of: shape defects and raw surface defects. However, as is known from a review of the technical literature, the vast majority of raw surface defects are a consequence of internal defects, primarily gas porosity. Therefore, a cautious conclusion can be drawn that further analysis should first be applied to these types of defects. However, this type of analysis on the basis of the Ishikawa diagram alone should be approached with great caution, as it is often easy to attribute a significant number of detailed causes, for example, in the process under study due to the appearance of defects in the finished products (thus easily identifiable) and, for example, internal defects, the disclosure of which requires additional research described in smaller numbers, and in fact account for the vast majority of all defects. Therefore, in the next step, casting defects were analyzed using a Pareto-Lorentz diagram.

5. Analysis of casting defects using the Pareto-Lorenz diagram

To make a detailed analysis of defects arising in the die casting process, a periodic quality report of manufactured die castings was analyzed. Based on it, a set of basic casting defects influencing the necessity of rejecting parts due to quality deficiencies was distinguished.

Those defects were singled out, which in the vast majority of cases directly contributed to the scrapping of rejected details. In some cases of revealed defects, due to the slight reduction in quality as well as the possibility of appropriate correction/repair/additional processing, such as puttying of surfaces where pores of less than 3 mm in size occurred after basic processing, it was possible to restore the final selection to the assumed quality level.

The occurrence of the main casting defects depending on the temperature value of the EN AC-435000 liquid alloy is shown in Figure 3. The main element influencing the number of defects in a given production cycle was the temperature of the liquid alloy. The highest number of casting defects, occurred at a temperature of 735ºC and amounted to as much as 49% of all manufactured products. The lowest percentage of defective products was obtained in the production cycle at 760ºC and was 19%. At a temperature of 775ºC, the percentage of defective castings was 39%.

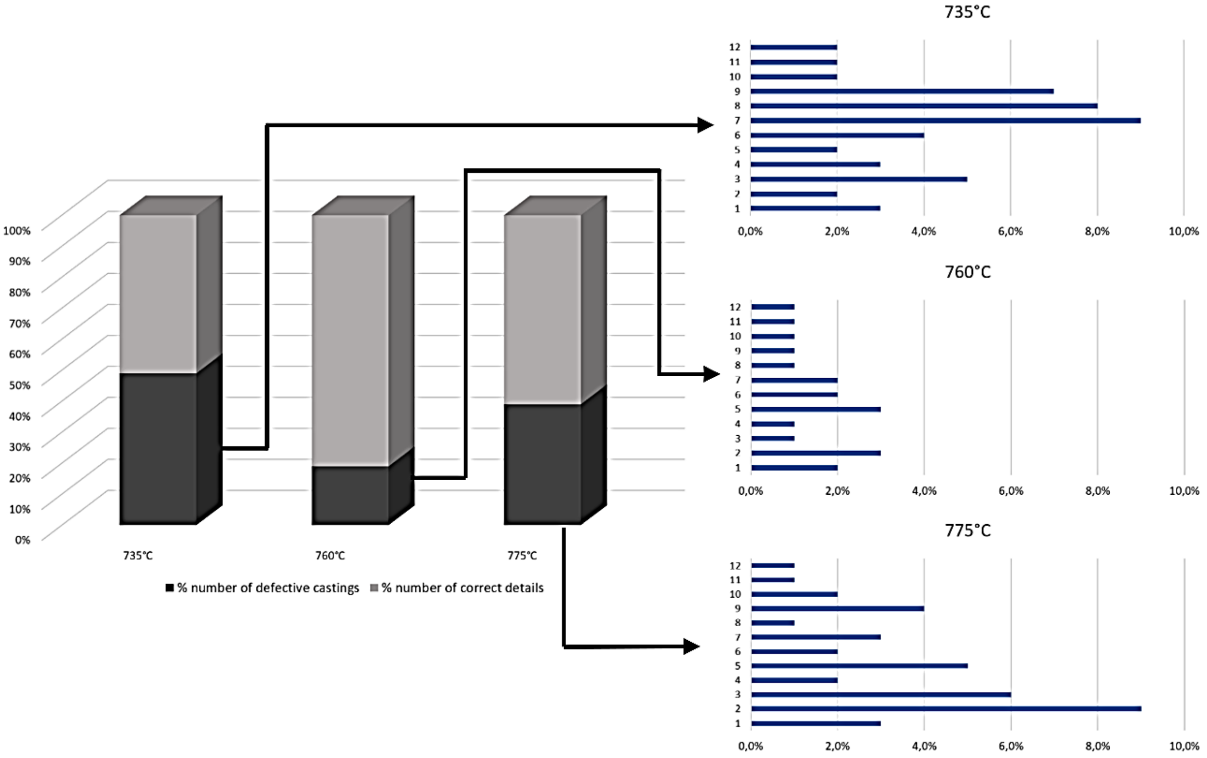

Figure 3. Occurrence of major casting defects depending on the temperature value of the EN AC-435000 liquid alloy, where 1. Gas blisters, 2. Dressings and shrinkage cavities, 3. Breakouts, 4. Mechanical damage, 5. Sealings, 6. Non-metallic inclusions, 7. Cracks, 8. Underfills, 9. Leakage, 10. Flat surface folds, 11. Seam welds, 12. Other.

With the use of computer analysis in conjunction with finished product inspection, it was possible to determine the exact type of individual defects that contributed to the need to reject the workpiece. Table 2 shows, ranked from most to least common defects in the case under review.

Table 1.
Ranking of the most common casting defects in the case study

No. of casting defect	Type of casting defect	Percentage of defect	Cumulative share
2	Dressings and shrinkage cavities	25%	25%
5	Sealings	20%	45%
7	Cracks	10%	55%
1	Gas blisters	9%	64%
6	Non-metallic inclusions	8%	72%
12	Other	6%	78%
8	Underfills	4%	82%
11	Seam welds	4%	86%
4	Mechanical damage	4%	90%
9	Leakage	3%	94%
10	Flat surface folds	3%	97%
3	Breakouts	3%	100%

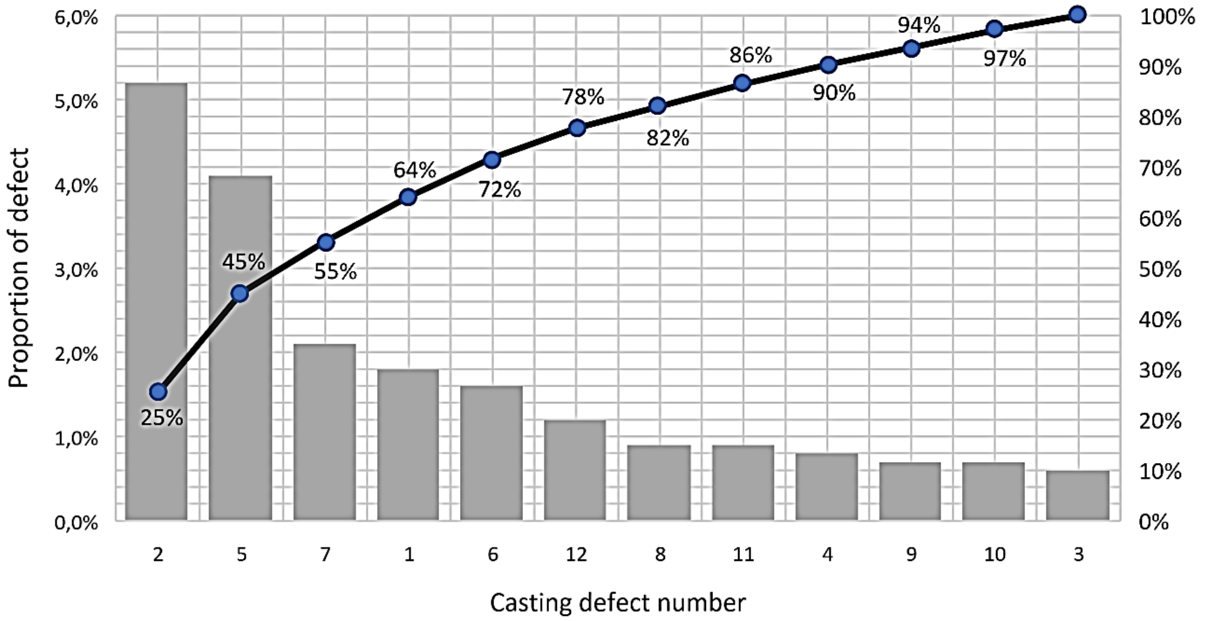

Figure 4. Pareto - Lorentz chart of casting defects (defect numbers according to Table 2).

Based on the data in Table 1, a Pareto-Lorenz chart was drawn up (Figure 4), for the determination of courses of action leading to a reduction in the production rate of defective details.

Analysis of the data allows us to note an even distribution of the causes of defective details. The first six of the listed defects, account for 78% of the total defects and the remaining six defects of the details, account for only 22%. This means that, according to the assumptions of Pareto analysis, in order to obtain a clear rationalization effect, it is necessary to evaluate the causes of the defects and their removal for the following defects: Dressings and shrinkage cavities (25%), Sealings (20%), Cracks (10%), Gas blisters (9%), Non-metallic inclusions (8%) and other (6%).

6. Summary and conclusions

In accordance with the stated goal, the use of the Ishikawa diagram made it possible to classify casting defects for the general categories adopted. Then, based on materials from computer analysis of workpieces as well as inspection of finished products, a Pareto-Lorenz analysis was carried out, thanks to which the defects occurring in castings were ordered according to their degree of importance. The first four defects listed turned out to account for 78% of all defects occurring in the production process. The result of this analysis was to take the necessary measures to minimize the most significant casting quality problems:

- systematic verification of the chemical composition of the EN AC-435000 alloy, and in the event of non-compliance, supplementation of missing batch components,
- control of the range of crystallization, i.e. the temperature of liquidus, solidus and eutectic crystallization, with particular attention to the minima and maxima of these parameters, especially the superheating temperature of the liquid alloy, due to the possibility of causing an increase in the degree of gasification of the alloy, and thus an increase in the porosity of the finished casting,
- more frequent verification of the system for temperature measurement, throughout the production process,
- additional control of the cooling rate, as well as heat dissipation,
- minimization of turbulence during casting from the melting furnace and during mold filling,
- increased attention to the cleanliness of the metal bath,
- increased care during transport and supervision of the correct operation of the system for knocking the casting out of the mold.

Based on the study, the following conclusions were made:

1. The most significant defects contributing to casting rejection are defects related to gas porosity of the alloy. These defects are most often due to poor chemical composition of the casting alloy, inadequate solidification temperature range, volume change during solidification, inadequate cooling rate and heat dissipation, and the presence of non-metallic inclusions.
2. Metal quality control should begin with the melting of the batch components. Eliminating irregularities at this stage of production will contribute to a significant reduction in casting defects.

3. Pareto-Lorenz analysis illustrates the unevenness of the distribution of causes in relation to the number of defects present in the workpiece. The principle that 80% of the effects derive from 20% of the causes should not be taken literally, however, in the studied alloy, 6 defects, accounted for 78% of the total.
4. In order to minimize the occurrence of casting defects, it is necessary to introduce: inter-operational quality control, supervise the technological parameters of the die casting process (temperature, time, pressure), increase the supervision of supervisory personnel, influence the self-awareness of employees through a series of courses and training.

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