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INVESTIGATION OF DEFECTS OCCURRING IN THE CASTING SHOP PROCESS OF CERAMIC SANITARYWARE ON THE FINAL PRODUCT

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Abstract: When the export values of ceramic sanitaryware in Türkiye are analyzed, it is seen that the data for the year 2022 of ~660 million dollars continues to increase. In the sector, which reaches an annual average increase of 100 million dollars, the amount of production as well as the design demands change and shape the market. The most important difficulty factors in design are due to the fact that the products in the sector have large sizes, complex shapes and the most human-made production stages. When these factors are compared with other ceramic sectors, it is revealed that although industrialization has increased in the production of ceramic sanitaryware, the lack of production amount and the excess of faults are among the biggest problems. Glaze faults are the leading faults observed in the final product, and since this problem is not recyclable, it harms the ceramic sanitaryware industry in terms of cost. In this study, the glaze faults reflected in the final glazed products originating from the casting shop stage, which attracts attention in this field due to its large size and whiteness and there is not much data for the vitreous ware industry in the literature, have been studied. In the study, which was carried out with the aim of detecting and eliminating some faults in industrial production and creating data for the literature, faults arising from mechanical evenings used in classical and pressure casting benches and material residues used in retouching processes were determined. These faults were produced on the basis of the laboratory and the characterization of the glazed faulty products was made. It is concluded that production losses can be reduced by eliminating these problems, consequently increasing quality and productivity.

Keywords: Sanitaryware, Casting department, Glazing, Ceramic manufacturing defects

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1. Introduction

Ceramics is an area that consists mainly of shaping and firing kaolin, quartz, feldspar and clay raw materials and provides functional use in the industrial sense. Sanitaryware (also known as vitrified ceramics) serves the industry as an important industrial production branch of ceramics, which has an important place in the ceramic industry in terms of providing hygiene and ease of life to people. Washbasins, toilet bowls, urinals, shower trays, etc. are the articles manufactured in this sector. The products are sintered at ~1200-1250°C and are in the scale of products that are difficult to manufacture, as they are large-sized, durable and low-water absorption products with a glassy glaze layer covering them. Although these products can be colored, they are preferably produced in white color as it is suitable for customer demand (Canduran ve Ural, 2019; Mete, 2020; Taykurt Daday, 2012).

As seen in Figure 1, different textures and impurities provide artistic effects in artistic ceramic production. However, in vitrified products, which are an industrial production branch, these images visually distort the effect as seen in Figure 2. Since they are relatively large in size, these products go to waste which has a negative impact on production in terms of raw materials, labor, energy and time. These faults can also be seen in a porcelain plate or ceramic tile product, but the biggest loss is more visible in the sanitaryware industry due to its larger size (Fortuna and Fortuna, 2017; Fraser, 2005).

Many studies have been done and are being carried out on ceramic defects in areas such as tableware and the tile sector, which require more patterns and designs. Efforts to eliminate these faults and possible causes of defects are determined, and some of the main faults in the literature are seen in Figure 3.

Figure 1. Some glaze defects used as artistic effects in artistic ceramic products (Berberoğlu, 2015; Genç ve ark., 2018; Genç, 2010; Taşkın, 2009).

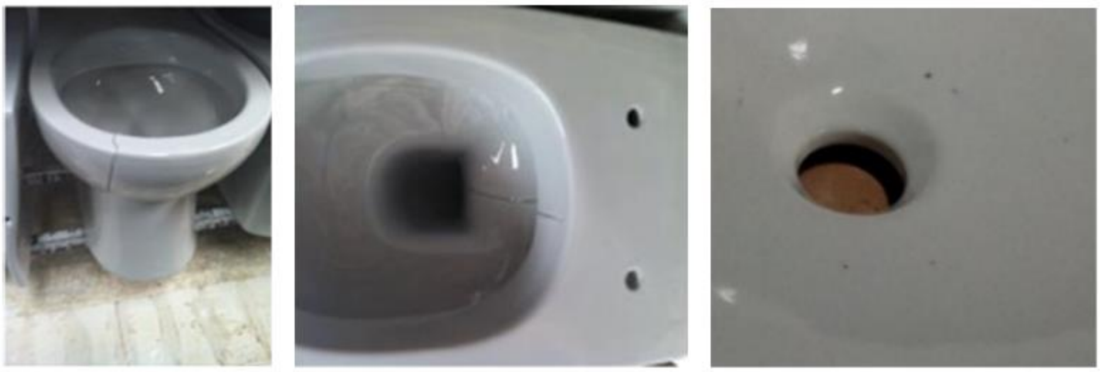

Figure 2. Manufacturing defects on some vitrified products.

Figure 3. Some ceramic glaze defects (Hopper, 2023).

Casting shop related defects in vitreous ware are generally in the literature; voids, points, lines, cracking, explosions due to plaster residues, deformations caused by uneven drying and air bubbles during filling. However, there are also faults that appear in the final product. These faults can be caused by various components and, in a sense, by human faults (Fortuna and Fortuna, 2017; Kurama ve Sarı, 2013).

In this study, the effects of defects occurring from the casting shop may occur in the final product stage besides the pre-sintering stage, and especially the effects of defects originating material based issues and their effects on the microstructure were investigated.

2. Materials and Method

Five of the materials utilized in the slip casting that cause the most faults were selected and these materials were applied on the specimen plates. Although the visuals of the faults on the plates in the experimental studies seem to be major, these defects are considered as minor in production. In fact, due to the plastic or polymeric materials used, it may move away from the body at ~250 °C during the sintering phase and cause defects such as air, crater or pinhole defects. Semi-finished products and raw materials used in factory conditions and production were supplied from Ece Bathroom production facility. Microstructure studies (SEM) of the study were performed by scanning electron microscope and chemical composition analysis (EDX). SEM/EDX images were measured with Zeiss Supra 50VP Brand device.

2.1. Casting Shop based Faults

2.1.1. Defects due to green scotch

Green scotch is a material that is generally used for retouching the surfaces of semi-finished products containing 18% moisture from casting. It is especially used for rounding corners. It can also be used in semi-finished products after drying. Many apparatuses are used during the retouching in the casting shop, but since the green scotch comes into contact with the product with plenty of water, they can be buried in the product from time to time and cannot be noticed in the process (Figure 4).

Figure 4. Green scotch (Right) and defects due to green scotch (Left).

2.1.2. Die casting machine materials

Pressure casting benches are different from conventional casting benches, they are more mechanical and have many moving and rotating parts. Machine elements such as belts or bearings are used in the rotational movements of these machine parts or the movements of the moving parts. Lubrication processes are also carried out to prevent the wear of these elements. The presence of water in the working environment causes these oils to clump and stick to the products in cases where cleaning processes are not carried out in a controlled manner. In addition, the abrasions that may occur due to the friction of some parts against each other and the resulting metal slags also cause the formation of metallic stains (Figure 5).

Figure 5. Die casting machine slag materials (Right) and defects caused by them (Left).

Many sanitaryware products such as sinks and toilet bowls are produced on the pressure casting benches as seen in Figure 6. However, while the molds are being opened, especially in products such as large-sized toilet bowls or similar shower trays, metallic parts that are poured from the upper part of the counter due to friction cannot be detected because they are taken into the system by robots without human touch. These types of defects also appear as stain faults at the exit of the kiln.

Figure 6. Vitrified die casting machine from Ece Banyo.

2.1.3. Strip tape abrasive based defects

Strip tape abrasive is a hard, metallic abrasive type used in ceramic sanitaryware at the stage of semi-finished product control. This abrasive, which is generally preferred in the retouching processes carried out under the control of the products after drying, is used to ensure the rapid flow of semi-finished products. The reason for this is that it has a high ability to retouch, since it is a hard abrasive. After using this abrasive in the semi-finished product control process, the surface should be wiped with a damp cloth again and the touch-up marks on the surface should be closed. Since it is a metal-based material, it causes staining in case of any wear or breakage (Figure 7).

Figure 7. Strip tape abrasive (Left) and defects (Right) due to this abrasion.

2.1.4. Faults from abrasive materials

Box shaped abrasives are a different type of abrasive used in casting shop and used to perform surface treatments of products. It is a material that can be touched up without damaging the surfaces, since the eroding part is soft, box-shaped and has a sponge in the middle. In some cases, stains can be seen if this abrasive (silicon carbide) wears off and the wearing parts adhere to the surfaces. In addition, abrasive particles that dissolve in the retouching waters in the casting shop and adhere to the surface with slip particles also cause staining (Figure 8).

Figure 8. Box Abrasive (Left) and Related Defects (Right).

2.1.5. White abrasive based defects

This type of abrasives is generally used in the semi-finished product control phase. White color is the chief reason for this abrasive to be utilized in the retouching process of the semi-finished product, because the upper area of the product is alumina-based. This type of abrasive is more preferred because black spots are observed in silicon alumina based abrasives. However, it is observed that this material also causes defects (Figure 9).

Figure 9. White Abrasive (Left) and its related defects (Right).

3. Results and Discussion

3.1. SEM /EDX Analysis

3.1.1. SEM/EDX analysis of green scotch based defects

The green scotch-based defects seen in Figure 9 cause inclusions in the structure since the material is polymer-based. In the samples studied in a major scale, the material appears as a mound because it does not completely melt in the glaze. However, it is not completely combined in the glassy phase, and it shows itself as a separate formation from the structure, as seen the figures (Figure 10).

Since the green scotch is a polymeric material, it does not leave any residue after firing. The earlier melting temperature of the material, which is embedded in the glaze (i.e., if parts remain within the body), causes defect on the glaze surface.

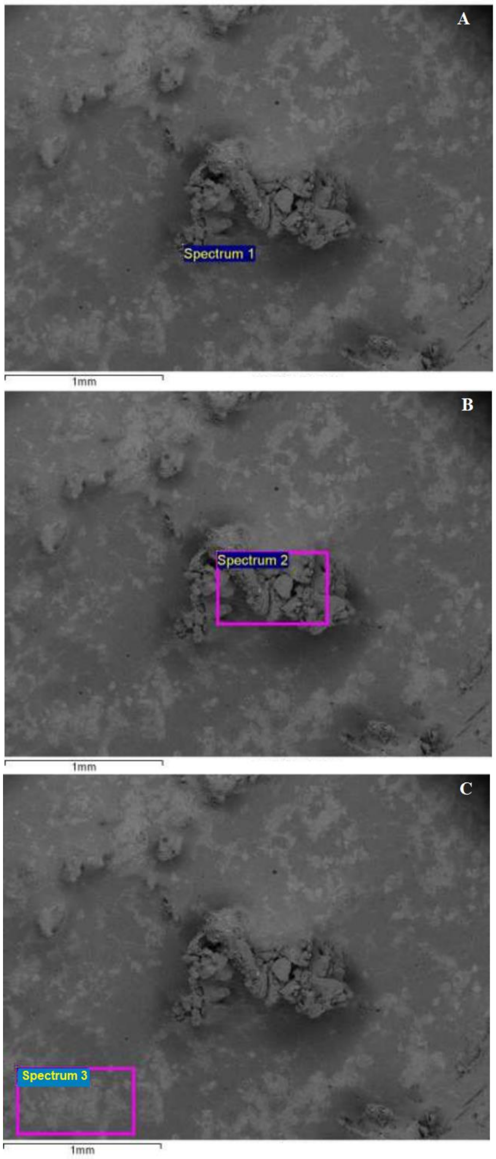

Figure 10. Some SEM Analysis of Green Scotch Based Defects A, B, C (Table 1 displays EDX analysis of the defects).

Since the green scotch is a polymeric material, it does not leave any residue after firing. The earlier melting temperature of the material, which is embedded in the glaze (i.e., if parts remain within the body), causes defect on the glaze surface.

Table 1. EDX analysis of green scotch based defects in Figure 10.

Ex. No	MgO	Al_2O_3	CaO	ZnO	SiO_2	Na_2O	K_2O	ZrO_2	Total
A	0	30.89	6.67	0	55.43	7.01	0	0	100
B	0	24.94	6.87	0	64.46	2.77	0.96	0	100
C	1.16	9.62	8.14	1.72	57.9	3.21	0.75	17.5	100

As seen in Table 1, in the analysis of the points where the Al_2O_3 ratio higher, ZrO_2 ratio is not observed in the structure, indicating the green scotch is causing defects in the regions. The defect of the natural opaque glaze structure is evidenced by the zircon ratio.

3.1.2. SEM/EDX analysis of defects due to die casting machine materials

Since there are iron particles in the machine oil, and the viscosity of the oil increases and becomes semi-solid due to friction, iron defects are encountered on the product surface. Also, assuming that the oil lowers the surface tension, it is likely to cause glaze collection in cases where the body absorbs the oil (Figure 11).

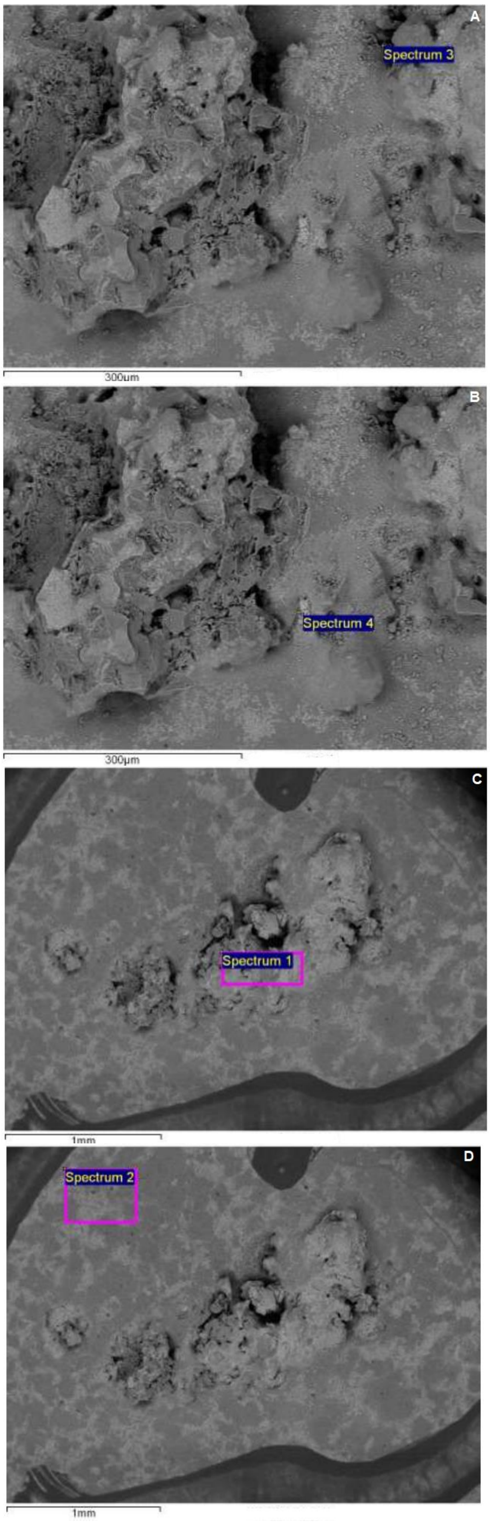

Figure 11. Some SEM Analysis of Defects Due to Die Casting Machine Materials (A, B, C, D) (Table 2 displays EDX analysis of the defects).

The high Fe_2O_3 ratio in the point analyzes in Table 2 shows that the parts poured over the machine are iron-containing. However, although there is a structure that creates a depression in the iron structure, it is seen that the other impurities that come with the iron do not melt completely, allowing the structure to remain rigid.

Table 2. EDX analysis of defects in figure 11 due to die casting machine materials

Ex. No	MgO	Al_2O_3	CaO	Fe_2O_3	ZnO	SiO_2	Na_2O	K_2O	ZrO_2	MnO	Total
A	0	35.22	0	3.3	0	58.1	2.76	0	0	0.61	99.99
B	0	0	0	100	0	0	0	0	0	0	100
C	4.55	17.66	4.1	24.47	4.18	43.27	0	0.85	0	0.92	100
D	1.14	9.27	6.21	0	1.39	58.96	2.84	0	20.2	0	100

3.1.3. SEM/EDX analysis of tape abrasive based defects

The tape abrasive is made of hard metallic materials. When seen under the glaze, it creates iron stains on the glaze surface. It has been observed that since it is placed as a whole piece in the figure, it does not spoil the glaze surface and behaves like a glaze in EDX analyses (Figure. 12).

Due to the application of the defect as a major part in the experimental studies, the abrasive remained under the glaze surface without melting and it was observed that there were glaze surfaces in the SEM/EDX analyzes. It has been determined that the EDX analysis, which provides a homogeneous image of the structure, also supports this idea (Table 3).

Table 3. EDX analysis of tape abrasive-based defects in figure 12

Ex. No	MgO	Al_2O_3	CaO	ZnO	SiO_2	Na_2O	K_2O	ZrO_2	Total
A	1.28	11.47	7.5	0.72	70.77	4.66	0.51	3.09	100
B	0	4.24	5.66	0	43.97	2.2	0	43.93	100
C	1.05	7.9	8	0	56.22	3.77	0	23.07	100.01

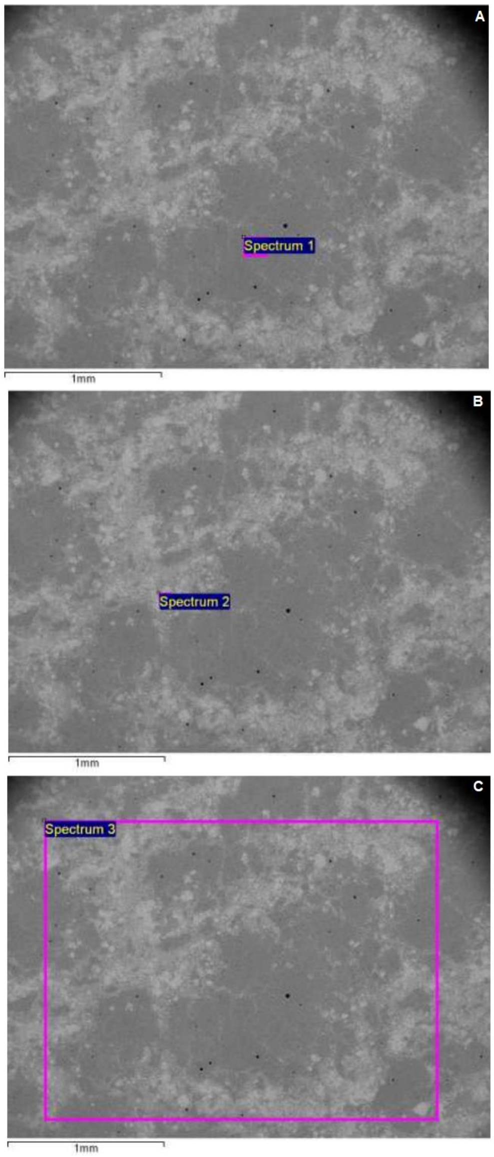

Figure 12. Some SEM/EDX Analysis of Tape Abrasive Based Defects (A, B, C) (Table 3 displays EDX analysis of the defects).

3.1.4. SEM/EDX analysis of box abrasive based defects

Box abrasives are applied on semi-wet products in the casting process. Especially the inner chambers of the toilet bowls and the fluffy parts on the outer surfaces are cleaned with these abrasives. For this reason, it is desired that this product should be hard. However, in the SEM images, it is seen that the SiC particles cause crystallization in the structure and are clustered locally (Figure 13).

As seen in Table 4, CO_2 formation was found that was not observed in other EDX analyzes. Another oxide seen here is SiO_2, proving that the material is SiC. In the results obtained from the faulty areas, it was determined that the glaze deteriorated on the surface and the ZrO_2 ratio was not found because the SiC material remained unmelted (Hasanuzzaman et al., 2022).

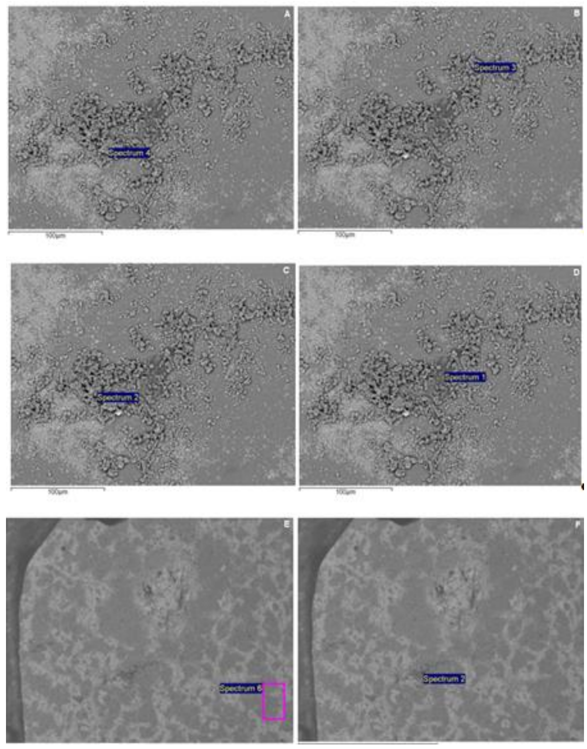

Figure 13. Some SEM/EDX Analysis of Box Abrasive Based Defects (A, B, C, D, E, F) (Table 4 displays EDX analysis of the defects).

Table 4. EDX analysis of box abrasive based defects in figure 13

Ex. No	MgO	Al_2O_3	CaO	ZnO	SiO_2	Na_2O	K_2O	ZrO_2	CO_2	Total
A	0	20.16	0	0	79.84	0	0	0	0	100
B	0	1.4	0	0	98.6	0	0	0	0	100
C	0	33.11	0	0	66.89	0	0	0	0	100
D	1.05	3.37	2	0	16.97	0	0	0	76.61	100
E	0	2.65	1.11	0	14.22	0	0	0	82.02	100
F	1.09	9.7	6.68	1.71	66.03	2.97	0.38	11.43	0	99.99

3.1.5. SEM/EDX analysis of white abrasive based defects

Since white abrasives are based on alumina silicate, it causes deterioration on the surface. The black spots seen on it are caused by the falling of the sponge pieces caused by friction and burning on the surface. The appearance of abrasive pieces on the glaze surface ensures that there are regions in the glaze structure as in the 2nd figure in Figure 14. As examined in the SEM images, it is seen that the alumina silicate layers deposited on the surface tend to mullite structures and begin to turn into a rod-like form. This causes refractory structures within the glaze, thereby distorting the appearance of the glaze (Figure 14).

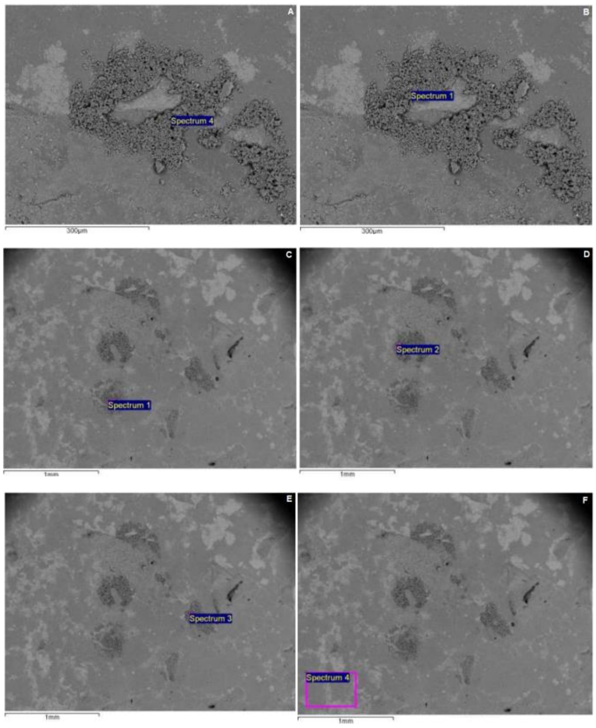

Figure 14. Some SEM/EDX Analysis of White Abrasive Based Defects (A, B, C, D, E, F) (Table 5 displays EDX analysis of the defects).

It also shows itself in EDX analyzes with the decrease in zircon ratios in which the glaze structure is deteriorated. The increased alumina ratio coincides with the EDX values taken from the samples (Table 5).

Table 5. EDX analysis of white abrasive-based defects in figure 14

Ex. No	MgO	Al_2O_3	CaO	SiO_2	Na_2O	K_2O	ZrO_2	Total
A	0	25.77	0	74.23	0	0	0	100
B	0	16.14	0	83.86	0	0	0	100
C	0	32.55	0	67.45	0	0	0	100
D	0	23.25	0	76.75	0	0	0	100
E	0	32.47	0	67.53	0	0	0	100
F	1.46	9.78	5.56	63	5.95	0.29	13.94	99.98

4. Conclusion

The casting is one of the first stages of production, and the defects that occur here are sought in the next process rather than the final product. However, in the study, it is revealed that these defects can also affect the final product and the use of the materials utilized properly and by changing will affect the quality of the final product. In this respect, it can be said that some types of defects, which are generally seen as workmanship defects, may also be caused by material deformations and it is important to detect this by the production foremen.
It has been observed that material-related defects may be polymer-based, as well as from hard materials with refractory properties such as metallic or SiC. When these defects are characterized, they can differentiate from the normal opaque vitrified glaze structure and create crystallized or deformational images. Sometimes the change in the ratio of alumina, sometimes silica, and in some cases, zircon, guides us to determine the damages caused by these materials to the structure.
Even if the ratio of the materials used is relatively low, it has been observed that it affects the crystallization in the glaze structure and causes staining and deterioration on the final product. SEM/EDX analyzes play an active role in determining the extent of damage to the product at the final stage.
Thus, it is concluded that production losses can be minimized by eliminating these problems, consequently increasing quality and productivity.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	N.D.C.	E.C.	C.E.I.
C	50	25	25
D	50	25	25
S	50	25	25
DCP	50	25	25
DAI	50	25	25
L	50	25	25
W	50	25	25
CR	50	25	25
SR	50	25	25
PM	50	25	25
FA	50	25	25

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans. The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to.

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