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Nonlinear cracking behavior of 2083 and 2083 ESR stainless steel used in core of injection mold

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ABSTRACT

In this study, it is aimed to investigate nonlinear surface crack of 2083 stainless steel used in core of injection mold. Strength properties and microstructure of the material directly affect the final product properties and quality. Stress in the structure of steel occurs resulting from shaping and cooling during solidification. It is possible for the same stressesto occur in the structure of the steel that is subjected to machining to produce any mold or mold component from a steel whose production operations have been completed. These stresses that may cause dimensional changes during shouldbe removed by annealing at a suitable temperature according to the type of steel used. This paper focused on the non- linear surface cracks which have been observed on the 2083 stainless steel used in core of injection mold. Also 2083 ESR (Electroslag Refining) stainless steel has been used for production injection mold in this study. It has not been ob- served any surface cracks. The same heat treatment with different temperature and time has been performed on the 2083and 2083 ESR stainless steel. The metallographic analysis, chemical composition and hardness test have been per- formed for comparative analysis. It has been found that the 2083 stainless steel hardness value lower than 2083 ESR stainless steel at the same heat treatment process. It can be concluded that 2083 stainless steel has a coarse grain. It means that the heterogeneous microstructure negatively affects mechanical properties.

Keywords: Surface cracks, 2083 stainless steel, 2083 ESR stainless steel, metallographic analysis, injection mold

1. INTRODUCTION

Recently, PolyEthylene Terephthalate (PET) is widely used for production of bottle/container due to its excellent mechanical and barrier properties [1]. PET bottle is firmly established in the global packaging market with dynamic annual earnings. The versatility of PET in termsof size, shape and functionality is one of the factors that make it stand out in the market. The plastic bottle market is growing with increasing demand for polyethylene terephthalate (PET) plastic bottles due to their recyclability. In addition, the increasing production of polyethylene terephthalate (PET) plastic bottles due to their durability,reliability and environmental friendliness increases their cost-effectiveness. Thus, it also enables to increases the growth industry. In other words, the increasing demand for reusable plastic bottles due to increasing environ- mental awareness gives further impetus to market growth. The global polyethylene terephthalate PET bottle market reached US$ 565.93 Billion in 2020 driven by increasing demand for polyethylene terephthalate (PET) plastic bottles. It has been expected to reach USD 781.90 Billion by 2028, displaying a CAGR of 3.87 % from 2021-2028. The PET bottles production process is de- fined by two process stages which is injection and blowing process. The machine that can be called conventional production method is widely used to produce injection and blowing molding process. Machining is oneof the most common manufacturing methods where thefinal shape is given by traditionally removing shavings from the metal material surface with cutting tools. The injection form occurs by stretching and blowing at the same time during the process. This process is performed in a mold which has a desired shape, technical and physical properties. The process stability is directly affecting the final product quality, uniformity in form distribution because of thermomechanical process [2]. The preform isobtained by injecting polyethylene terephthalate (PET) in the mold at a certain temperature. The temperature distribution along the length of the performance is one of the most important parameters in this stage. The temperature directly affects consistency of raw material and influences kinematics during preform forming process. The point between the blown perform and cooler mold walls reduce the blown perform temperature because of temperature difference. This temperature difference enables the solidification of plastic initiates [3]. The production phase in pet blow molding machines takes place in the feeding unit of the blow molding machines of the pre- forms produced in the injection machines. The preform heating process is one of the most important stages for the bottle to take the desired form in the mold. It is important to ensure that the same wall thickness is achieved in every part of the bottle [4]. The blowing phase is performed at high pressure and in a very short time. The first blowing of 4-6 bars is performed in the preform. Then this pressure reaches about 15-40 bars that is value completed thefinal shape of bottle. Nonuniform temperature distribution of preform, waste air pressure in mold directly affects final product quality. Also, the

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material selection which is used in injection and blowing mold production is one of the most crucial points for ensuring final product quality and mold life. The internal stress which canbe raised from machining process can be caused by non- linear surface cracks on the material in progress of time. Much research has been studied about that the under- standing of metal deformation and fracture, but these mechanisms cannot be explained exactly. Recently the studies of single crystals which have a simple structure have been examined for understanding these mechanisms [5]. Fatigue cracks are considered to arise from a variety of mechanisms in steels. These mechanisms can be cate- gorized such as surface at machining marks, grain/phase boundaries defects or internal metallurgical defects [6]. Ithas been reported that the formation of cracks can occur only if there are stresses. Also, it has been reported that the level of the ductility of the steel is directly affected by the level of stresses which are responsible for crack forming in the related material [7]. Steelmaking technology has a critical role in ensuring high-quality steel melts because of formation of the reoxidation of melt occurs. Thus, this cause to increase inclusion content in the raw material [8]. The electroslag refining processadmitted process for the high-quality raw materials pro- duction [9]. Electroslag Refining process can be defined is one of the refining processes. This process provides a thin slag layer solidifies on the surface of the raw mate- rial. Also, this ensures a smooth surface quality [10]. ESR process ensures to obtain raw materials which have a minimum inclusion content, good chemical homogeneity, and homogeneous structure leading improvement in mechanical properties [11]. It is possible to obtain the highest mechanical properties such as ductility and toughness by using ESR process compared to conventional process [12].

2.1. MATERIAL AND METHOD

2.1.1. CORE

The injection blow molding machine has a hot and cold two different part contain entire injection unit and table which has a multi-impression mold assembly mounted on the rotary table [13]. The injection mold contains different components which have different dimensions, wall thickness, length. The core is one of the most important components of the injection mold structure. On the other words the core has been used forforming of PET preform during solidification of plastic initiate's process. Figure 1 shows the core design.

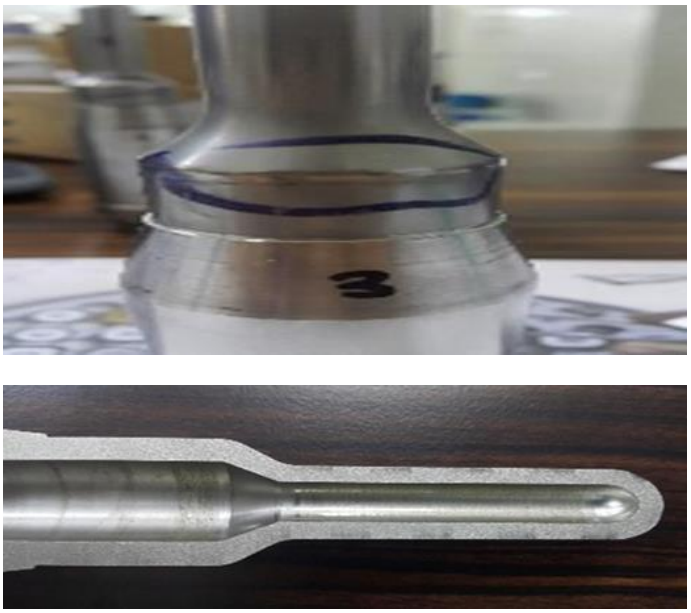


Figure 1. The core design2083 and 2083 ESR stainless steelchemical composition analysis

2.1.2. 2083 and 2083 ESR STAINLESS STEEL CHEMICAL COMPOSITION ANALYSIS

Stainless steel has a wide range of applications for various purposes in many different industries due to their properties such as corrosion resistant, high tensile strength, easy formation [14]. Table 1 and Table 2 show the chemical composition of 2083 and 2083 ESR stain- less steel has been used in this study. The chemical analysis has been performed using spectral analysis.

Table 1. Chemical composition of 2083

C	Mn	P	S	Si	Cr
0.358	0.227	0.0184	0.0005	0.454	13.2
Fe	**Mo**	**Ni**	**Cu**	**Pb**	**Al**
85.1	0.762	0.156	0.0605	0.0020	0.0166
Co	**Ti**	**V**	**W**	**Sn**	**B**
0.0204	0.0055	0.0466	0.0226	0.0045	0.0002

Table 2. Chemical composition of 2083 ESR

C	Mn	P	S	Si	Cr
0.417	0.730	0.0181	0.0037	0.962	13.0
Fe	**Mo**	**Ni**	**Cu**	**Pb**	**Al**
84.4	0.0113	0.179	0.0405	0.0020	0.0122
Co	**Ti**	**V**	**W**	**Sn**	**B**
0.0232	0.0076	0.0728	0.0161	0.0056	0.0006

2083 stainless steel is equivalent to AISI 420 steel. Main

characteristics of DIN 2083 are listed such as a good atmospheric resistance, excellent machinability in annealed condition, good wear resistance.

3. EXPERIMENTAL

3.1. CORE PRODUCTION PROCESS

The core production process contains different machines such as roughing cut, perforation, heat treatment,finish. The heat treatment has been performed for stain- less steel is given Table 3.

Table 3. Heat treatment process for 2083 and 2083 ESR stainless steel

Step-1	Pre-heating	650^0C, 1-2 hours
Step-2	Second heat-ing	800^0C, 1-2 hours
Step-3	Hardening	1020-1040^0C, 15-30 minutes
Step-4	Cooling	550^0C, 2-3 minutes
		30^0C, 2-3 hours
Step-5	Tempering	300^0C, 5-6 hours
		150-200^0C, 2-3 minutes
		30^0C, 2-3 hours
Step-6	Tempering	300^0C, 5-6 hours
		150^0C, 2-3 minutes
		30 ^{0}C, 2-3 hours

The hardening stage with 1020-1040 ^{0}C and 15-30 minutes is defined austenite point temperature. The cooling process was performed using nitrogen gases. The hardness of the material should be checked after the first tempering process.

4. RESULTS AND DISCUSSION

4.1.NONLINEAR SURFACE CRACKS

Figure 2 shows that the core has a surface crack. The internal hole surface quality of core tends to corrosion formation. Also, this corrosion causes cracks on the core surface.

Figure 2. Core surface cracks

4.2. HARDNESS TEST

Table 4 and Table 5 show the numerical data of ab- sorb energy, preexperimental and postexperimental. 150 Joule Hammer has been used during experiment. The hardness values which are obtained post-experimental arise from tensile and compression force. It has been found that the absorb energy exhibits a different distributionfor each test sample of 2083. It can be concluded that dross amount in internal structure of this material. Also, this impureness dispersed heterogeneously in the raw material.

Table 4. Test results of 2083 stainless steel

Test No	Absorb Energy (Joule)	Hardness (preexperimental) (HRC)	Hardness (postexperimental) (HRC)
1	21	19.5-21.5	10.9
2	37.5	19.5-21.5	13.3
3	34.1	19.5-21.5	10.15
4	12.1	19.5-21.5	13.25

Table 5. Test results of 2083 ESR stainless steel

Test No	Absorb Energy (Joule)	Hardness (preexperimental) (HRC)	Hardness (postexperimental) (HRC)
1	13.4	24.5-27.5	13.35
2	14.8	24.5-27.5	13.1
3	14.6	24.5-27.5	13.7
4	11	24.5-27.5	13.45

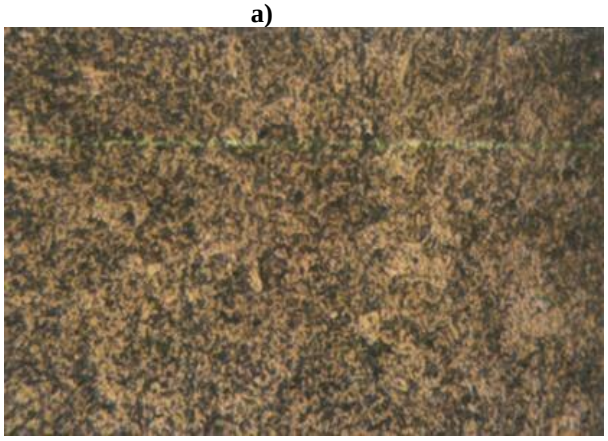
It can be seen clearly that 2083 sample has a lowerhardness value than 2083 ESR sample in Table 2. It can be concluded that 2083 sample has a coarse-grained than 2083 ESR sample.

4.1. METALLOGRAPHIC TEST

Spruers Transpol-2 sample preparation device was used. Also 60-120-240-400-500-800-1000-1200 Grit SiC emery and 1-3-6-9-

micron polishing broadcloth. The metallographic test was performed for different samples of the DIN 1.2083 stainless steel used in core of injectionmold. Thus, it was aimed to investigate different unit areas on the same base metal using metallographic test. These samples were categorized with 4 different sample numbers. Figure 3 shows sample 1 metallographic test with different magnification factor (200X and 500X) for 2083.

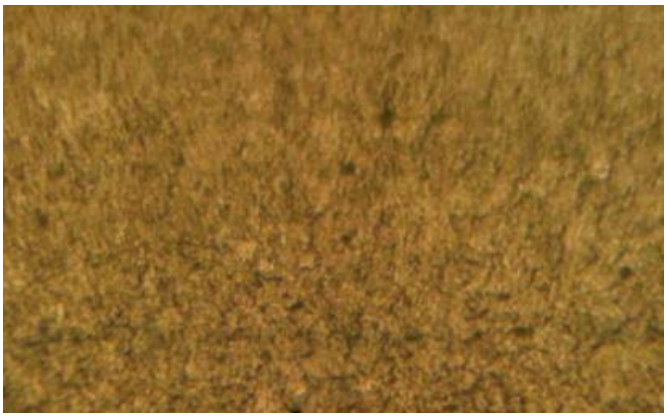
a)



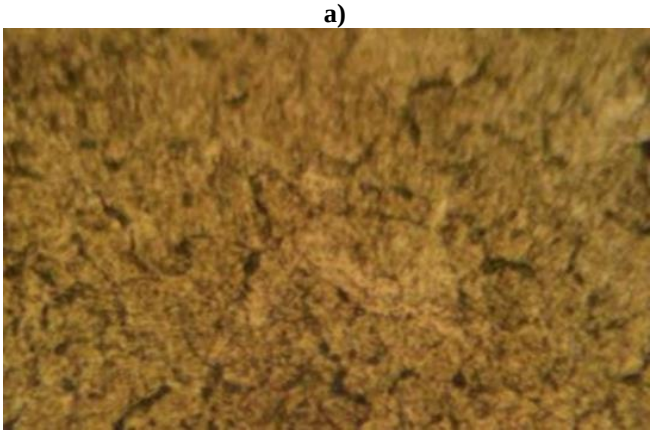
b)

Figure 3. Metallographic test of 2083 stainless steel with a) 200X b) 500X

It was observed that nonhomogeneous structure is based on martensitic-ferrite microstructure. Figure 4 shows sample 2 metallographic tests with different magnification factor (200X and 500X) for 2083 ESR stainless steel.



a)



b)

Figure 4. Metallographic test of 2083 ESR stainless steel with a) 200X b) 500X

It can be seen clearly that 2083 ESR has a martensite structure in Figure 4. The structure exhibits homogeneous characterization. Also, it was observed that the carbide precipitateness in the structure. This precipitate- ness can be related to the heat treatment process. Ni et al. has focused on the ESR process on the microstructureand mechanical properties of TiC particle reinforced 304 stainless steels. Also, they have observed that there is more uniform distribution in the microstructure [15]. Qui et al. have focused on the effect of ESR process on the inclu- sions. They have reported that ESR process remove the large inclusions and improve the distribution of inclu- sions [16]. Kim [17], Sawahata [18], Tanigawa [19], Li
[20], Xia [21] and Sakasegawa [22] have been reported that ESR process has significant affect the inclusion, microstructure, and mechanical properties of the reduced activated ferritic/martensitic (RAFM) steels.

5. CONCLUSION

In this study, the comparative analysis has been aimed between 2083 and 2083 ESR stainless steel in terms of hardness value, structural characterization. Also, the effect of heat treatment on the structure characterizationhas been analyzed. It can be concluded that the dross amount of 2083 stainless steel is higher than 2083 ESR stainless steel. This dross and can be defined as an im- pureness can be cause to heterogeneous structure in the raw material which is used for core production process. It means that impureness directly affects the mechanical properties of the raw material. And this impurityof the

microstructure causes stress during the machining process of raw material. It can be concluded that the ESRprocess provides minimum inclusion in the micro- structure of the raw material. Thus, it has not been observed that any surface cracks on the injection mold which is produced from 2083 ESR stainless steel.

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