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Analysis of Surface Cracking Defect of 304 Stainless Steel Deep Drawing Products

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ABSTRACT. *Aiming at the transverse cracking defect of 304 stainless steel deep drawing product (rice cooker inner liner) in the process of deep drawing, the martensite content, metallographic structure and mechanical properties were tested. The morphology of 304 stainless steel deep drawing product was observed by scanning electron microscopy, and the components of the defect were analyzed by energy dispersive spectrometer. Based on the experimental results and related research and analysis, it is inferred that the cracking defect of stainless steel inner tank is mainly caused by work hardening in deep drawing process, and small crack is formed due to inclusion shedding in steel, and crack extends further in plastic deformation.*

KEYWORDS: *304 stainless steel, deep drawing, inner tank, crack*

1. Introduction

Rice cooker is the most commonly used cooking utensils in our daily life. More and more intellectualization fills our eyes. Humanized design greatly facilitates our life. But the most important thing for a high quality rice cooker is its inner gallbladder. Usually, the material of the rice cooker inner liner can be divided into the following categories: stainless steel, aluminum, ceramics, and titanium alloy. 304 stainless steel not only has excellent corrosion resistance and intergranular corrosion resistance, but also its chemical composition meets the national hygienic standards for stainless steel tableware containers, so it has become a high-quality material for rice cooker inner gallbladder.

At present, the preparation of stainless steel inner liner is mainly obtained by stamping. Stamping is the process of turning materials into cylindrical or box-

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shaped objects, which is realized by punch and die. When the depth of stamping is more than 1.5 times the diameter of the object, the stamping can be called deep drawing.

The deformation-induced martensitic transformation of 304 stainless steel is prone to occur due to the large degree of plastic deformation during the stretch forming. For product processing, the appearance of deformation-induced martensite can easily lead to the intensification of deformation hardening, the decrease of plasticity and the cracking in the process of preparation, and the delayed cracking and stress corrosion is prone to occur when the product is used later[1-4]. In this paper, the cracking defects of 304 stainless steel deep drawing products in a batch were studied, and the causes of the defects were analyzed, which provided some reference value for avoiding similar defects in the future.

2. Appearance Analysis of Cracked Products

The macroscopic appearance of 304 stainless steel deep drawing product is a stainless steel inner liner for the rice cooker. The actual measurement shows that the inner diameter of the upper half is about 300 mm and the bottom is about 225 mm. The diameter of the disc used for deep drawing is about 485 mm, the thickness is 0.48 mm, and the drawing ratio of the product is 2.15. Its production process is as follows: wafer → first stamping forming (trapezoid) → second forming (modeling and edge closing).

As shown in Fig. 1, the crack of stainless steel inner liner occurs at the bottom of the side. The defect is a transverse straight line and runs through the whole cross section. The length of the crack is about 150 mm, and the defect is serious.

Figure. 1 Macro-morphology of 304 stainless steel inner tank

3. Analysis and discussion

3.1 chemical composition

The cracked stainless steel inner gallbladder sample was taken and its composition was tested by QSN750 II direct reading spectrometer. The results show that the composition of the base metal for stainless steel inner gallbladder meets the requirements of SUS304 steel. Md is the highest temperature of deformation-induced martensite transformation. It is usually marked by the temperature at which 50% martensite is produced after 30% cold deformation, i.e. Md30.

$$Md30=551-462*(C+N)-9.2*Si-8.1*Mn-29*(Ni+Cu)-13.7*Cr-18.5*Mo \quad (1)$$

According to the above formulas, the addition of copper in steel can reduce the Md30 value, reduce the degree of work hardening, and enhance the fluidity of materials during cold deformation, thus improving the drawing performance [5].

Table 1 Chemical composition of stainless steel (mass fraction, %) and Md30 (℃)

Steel	C	Si	Mn	P	S	Cr	Ni	Cu	N	Md30
304	0.046	0.44	1.06	0.025	0.0049	18.25	8.05	0.32	0.040	5.5

3.2 Martensite Content

The martensite content at the bottom, side and crack of the sample was detected. The results show that the martensite content at the bottom of stainless steel inner gallbladder is between 2.6% and 3.1%, which is in the normal range (see Figure 2).

Figure. 2 Determination of martensite content in the bottom of stainless steel inner tank

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The martensite content in the longitudinal plane of stainless steel inner liner products was measured. The martensite content ranged from 1 to 12 points from the bottom to the top. As shown in Fig. 3, the testing results at two different locations are basically consistent. The martensite content reaches a maximum of 19% at the top of the stainless steel inner gallbladder and a minimum of 1% at the bottom of the gallbladder.

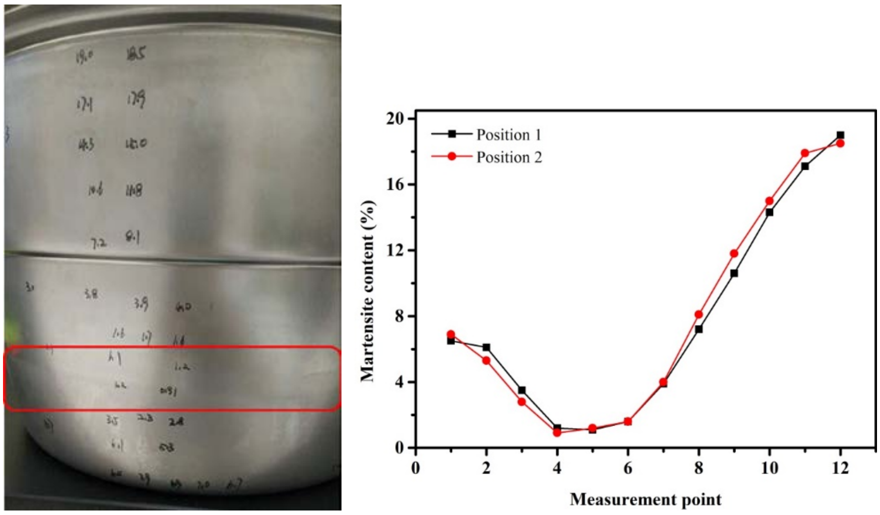

Figure. 3 Determination of martensite content in longitudinal plane of stainless steel inner tank

The measurement results at the cracking point show that the content of martensite is 8-11%, which is 2-5% higher than that at the same position from the bottom.

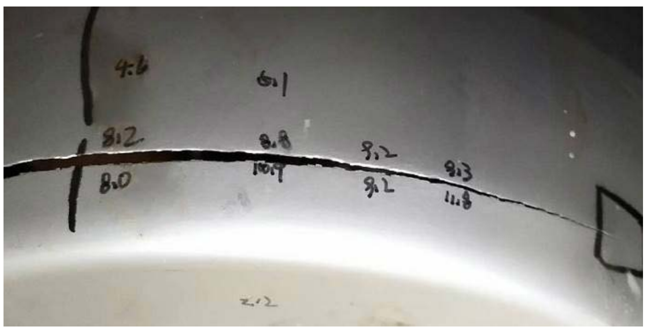

Figure. 4 Determination of martensite content at cracks in stainless steel inner tank

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3.3 Metallographic analysis

The metallographic structure of cracked rice cooker inner gallbladder was analyzed with batch stainless steel base material. The results show that the average grain size of the material is 8, and the grain size is fine, which is not conducive to extend.

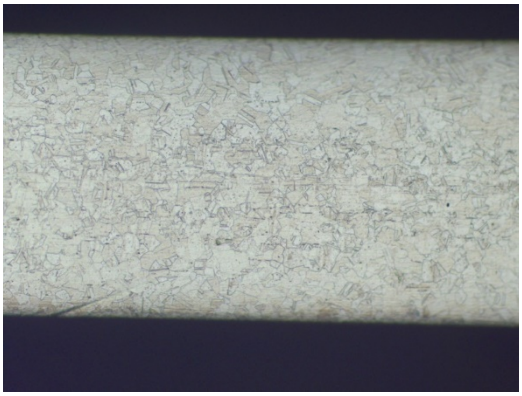

Figure. 5 Grain size of stainless steel sheet

3.4 SEM analysis

Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were used to analyze the cracking position. The microscopic analysis showed that there were pits in the defect, and the energy spectrum components showed that there were oxygen, silicon, calcium, magnesium, aluminum and other elements. It was speculated that the inclusion was calcium, silicon and aluminum oxides. The possible cause of cracking defect in stainless steel inner liner is inclusion shedding[6].

Figure. 6 Scanning Electron Microscope Analysis of Cracking Location of Stainless Steel Inner tank

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Table 2 Chemical composition of cracking position of stainless steel inner gallbladder, wt.%

	C	O	Mg	Al	Si	Ca	Cr	Ni	Mn	Fe
1#	0.20	7.79	2.22	1.33	3.11	3.27	16.58	5.73	1.47	58.30
2#		2.85	0.73	0.42	1.30	0.90	18.17	7.51	1.23	66.88
3#	0.29	1.35		0.27	0.75	0.22	18.76	7.94	1.29	69.14
4#		4.70	1.13	0.84	2.06	2.28	17.77	6.88	1.35	62.98
5#	0.33				0.4		18.99	8.08	1.20	70.99

3.5 Mechanical Performance Analysis

Tensile and hardness tests were carried out on the sample wafer and the bottom of the product. The experimental results are as follows:

Table 3 Comparison of Mechanical Properties of Samples

Sample	Tensile strength R_m /MPa	Yield strength $R_{p0.2}$ /MPa	Elongation rate A_{50} / %	Hardness /HV
Wafer	685	261	54.2	151
Bottom of product	678	256	52.3	268
JIS standard	≥520	≥205	≥40	≤200

From the analysis results in Table 3, it can be seen that the tensile strength, yield strength and elongation of the material have no obvious changes before and after processing, and the properties meet the requirements. After stretching, the hardness of the bottom of the product reaches 268HV, and there is an obvious work hardening phenomenon.

4. Conclusion

According to the results of cracking analysis of 304 stainless steel inner liner products, the following conclusions are drawn:

(1) The ultimate drawing ratio (the ratio of original diameter to processing diameter) of 304 is about 2.2, and the deep drawing ratio of inner liner products reaches 2.15, which is close to the limit and leads to cracking.

(2) There are pits in the cracks, and the probe results show that the inclusions may fall off. Cracks are caused by inclusions in deep drawing process, and then the cracks develop and extend.

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