International Journal of Applied Engineering Research ISSN 0973-4562 Volume 16, Number 3 (2021) pp. 175-180

Effect of Heat Treatment on Starwheel's Baseplate Lifetime of an Automatic Filling Machine

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Abstract

There are many factors that may cause problems during production process using an automatic filling machine. The main problem is the reduction of the starwheel's baseplate lifetime due to the friction and pressure applied by the bottles on the starwheel's baseplate component. The reduction of the starwheel's baseplate lifetime can significantly affect the automatic filling machine's performance. In order to increase the starwheel's baseplate lifetime, the structural material and the design of the starwheel's baseplate were modified. The influence of the heat treatment parameter on the performance of the starwheel's baseplate made of AISI 4140 was studied in this research. The performance tests were carried out directly on the automatic filling machine, followed by surface roughness measurements. The result show that lifetime of the starwheel's baseplates heat treated at an austinitizing temperature of 850 °C an tempered at 180 °C was higher compared to the other plates with different treatments.

Keywords: Starwheel, heat treatment, AISI 4140, hardness, automatic machine

1. INTRODUCTION

Engineering was done to alter the production process and solving issues that had occurred in that process. In mechanical engineering, there are many parameters that affect the engineering qualities. Overall consideration of most parameters had to be done to ensure that the mechanical engineering have fulfilled the desired functions and qualities [1].

A problem faced by an industry during its production process is the material performance of the starwheel's baseplate made of polymer POM, which is worn out after 12.000.000 cycle (6 months), causing breakdowns of production process and therefore the reduction of the company's revenue (Figure 1).

The purpose of this research is to have the most effective material for the starwheel's baseplate that can reduce friction and pressure that happens during the roll on process such that the overall production process can run efficiently and will eventually increase company's profit.

Selection of the right material is a critical point in mechanical engineering. There are many factors that have to be considered on engineering, such as material strength, stiffness, wear resistance, etc.

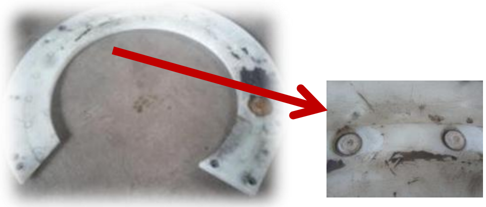

Figure 1. Damaged starwheel's baseplate

2. EXPERIMENTAL PROCEDURE

This experiment will use AISI 4140 that is a molybdenum chromium combined steel. Chromium content gives good hardness and the molybdenum content gives uniformity of hardness and strength. Desired mechanical properties of AISI 4140 include superior strength, good flexibility and good wear and tear endurance [2]. AISI 4140 can have a heat treatment.

Heat treatment process described as inserting material into cycle of temperature within certain amount of time, which is divided into 3 stages: heating, retaining temperature (immersion) and cooling. The purpose of retaining temperature on steel is to make sure that the temperature is uniform throughout its body [3]. The material composition of AISI 4140 can be seen in Table 1.

Tabel 1. Material composition of AISI 4140 [7]

Element	Percentage (wt%)
Carbon	0.380 – 0.430
Chromium	0.80 – 1.10
Iron	96.785 – 97.77
Manganese	0.75 – 1.0
Molybdenum	0.15 – 0.25
Phosphorous	≤ 0.035
Silicon	0.15 – 0.30
Sulfur	≤ 0.040

Starwheel's baseplate design process on automatic filling machine will use design thinking method. The steps are:

1. Empathize
   First step is to get empathic understanding about the issues that needed to be solved by identifying needs.
2. Define
   Information gathered during empathize step, analyzed and synthetized to define the main issues.
3. Ideate
   This step is to generate idea. All idea gathered to resolve main issues defined in define step.
4. Prototype
   On this step, Prototype, analysis and optimization will be done based on ideas generated in order to determine whether the design can meet the specification and performance, rejected or need modification. The result of this step is to have the optimum design.
5. Test
   On this step, test and evaluation will be done on the design. Test result on the prototype is the proof the design can meet the specification and performance targeted.

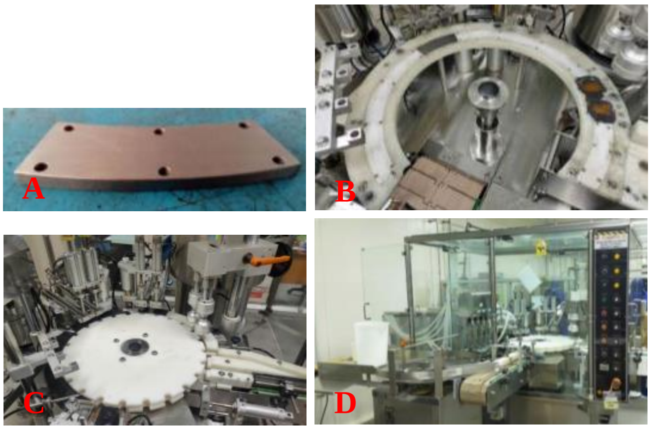

Figure 2. Testing steps on automatic filling machine (A) Processed AISI 4140 material, (B) Starwheel's baseplate installation on automatic filling, (C) Component checking for correct installation, (D) Automatic filling machine.

AISI 4140 was chosen to produce the starwheel's baseplate based on the design. Three samples of starwheel's baseplates were tested on the automatic filling machine. The 1st sample was the baseplate without heat treatment, the 2nd and 3rd samples with heat treatment. The steps of heat treatment are:

1. Preheating process until reaching 650 ºC for 2.5 hours. The purpose of the preheating process is to prevent thermal shock during the heating process.
2. Next process is austenization process until reaching 850 ºC for 2 hours. Phase occurred on this step is austenite.
3. Next is the quenching process using oil as the cooling media until the temperature of the material reach 70 ºC, for around 15 minutes. Austenite phase will change to martensite phase from the rapid cooling of AISI 4140 from 850 ºC to 70 ºC.
4. AISI 4140 then enters the first tempering process 180 ºC for 4 hours. Martensite will be fragile without tempering process because of the internal stress that formed during quenching.
5. Next process is cooling to room temperature followed by the second tempering process until reach 600 ºC for second sample and 180 ºC for third sample for 4 hours. The purpose for the second tempering process is to increase the hardness level.
6. After that hardness test using Vickers method conducted.

All three samples will be tested for ±1 million cycles on the automatic filling machine. Figure 2 shows testing step on automatic filling machine. After testing, the surface roughness test will be conducted using a testing device Mitutoyo SJ-301 (Figure 3) on 8 different points to have the average value of surface roughness and maximum depth value.

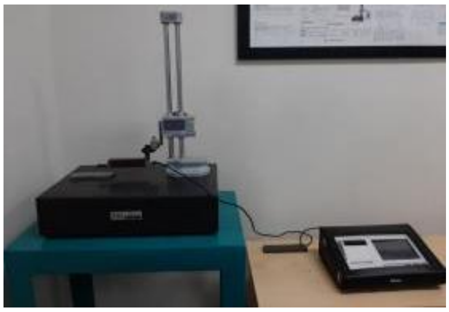

Figure 3. Surface Roughness Test Mitutoyo SJ-301

3. RESULT AND DISCUSSION

Starwheel's baseplate design process on automatic filling machine will use design thinking method. The steps are:

1. *Empathize*

This step will identify problems on PT. X's automatic filling machines.

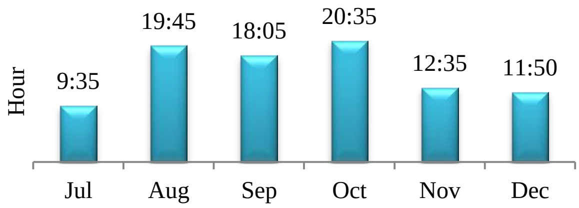

Figure 4. Starwheel's baseplate downtimes at the roll on pressing area in 2019

From the Figure 4, the average Starwheel's baseplate downtimes that occurred at the roll on pressing area is around 9 to 20 hours per Month in 2019. It showed that the

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 16, Number 3 (2021) pp. 175-180
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worn out starwheel's baseplate have a big impact on the production process, especially at the roll on pressing area.

2. *Define*

In this step, the factors that affect the Starwheel's baseplate at the roll on pressing area were determined. Then, the factors obtained were examined to create the ideal design for the starwheel's baseplate. The factors that were examined are the material, dimension, function, how the machine works, safeness, assembling method, maintenance process and materials cost (See Figure 5).

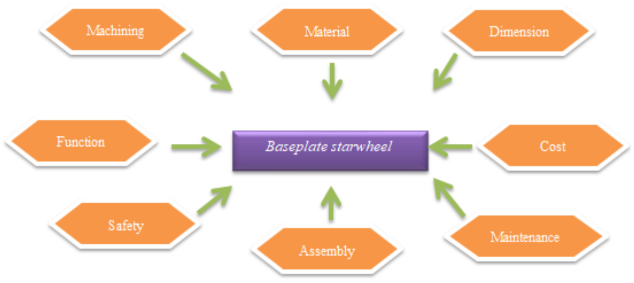

Figure 5. Factors diagram that affect starwheel's baseplate.

3. *Ideate*

Ideate step will generate idea to create solutions in designing starwheel's baseplate based on the issues that were determined in the define step.

4. *Prototype*

In this step, the factors that have been described will be analyzed and then the prototype will be made. The factors affecting the starwheel's baseplate design process are the material, the dimension and the materials cost (Table 2)

Table 2. The factors affecting the starwheel's baseplate design process

The Factor	Existing Condition	Designed Condition
Material	Polymer POM	A material that can withstand the heat treatment in order to have the desired mechanical properties
Dimension	Length : 393 mm Width : 90 mm Thickness : 4 mm	A dimension designed to reduce the stress when the bottle pressed on the baseplate
Cost	-	The cost is affordable

In this work, AISI 4140 will be used due to its ability to be heat treated to enhance its mechanical properties according to the needs. The expectation for using the AISI 4140 for the Starwheel's baseplate are:

1. It could withstand both the compression force and friction that happened between the bottle and the starwheel's baseplate
2. The bottles should not break during the filling process
3. The lifetime of the starwheel's baseplate could be extended.

Table 3 explained about a design that considered the dimension and the material cost. The dimension factor will reflect the stress done on the starwheel's baseplate and the material cost factor will explain about mass (kg) needed to make the starwheel's baseplate that will affected the price. To calculate the required mass, it will be calculated using equation (1):

$$m = \rho \; x \; v \qquad (1)$$

where m is the mass in kg, ρ the density in kg/m^3, and v the volume in m^3.

Table 3..The Analysis of the design, based on the dimension and the material cost

	Material	Dimension	Cost
Existing condition	Polymer POM	Length : 393 mm Width : 90 mm Thickness : 4 mm	-
1st design	AISI 4140	Length : 393 mm Width : 90 mm Thickness : 8 mm	7.85 g/cc density assumed
2nd design	AISI 4140	Length : 132 mm Width : 41 mm Thickness : 8 mm	7.85 g/cc density assumed
3rd design	AISI 4140	Length : 57 mm Width : 41 mm Thickness : 8 mm	7.85 g/cc density assumed

Figure 6. showed the 1st, 2nd, and 3rd designs that will be analyzed based on the dimension and the material cost.

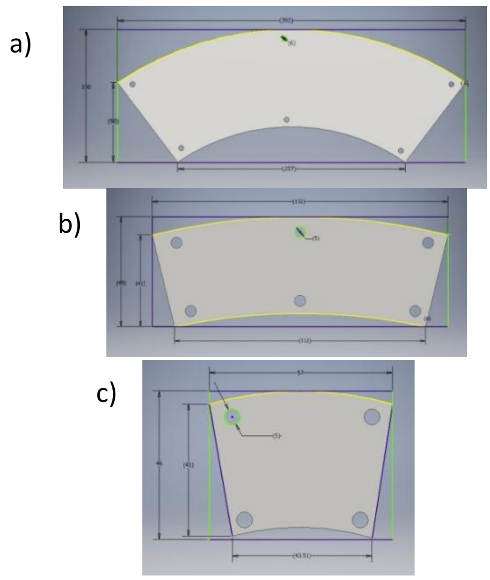

Figure 6. a) 1st, b) 2nd, and c) 3rd designs

As shown in Figure 7, the base of the bottle was not smooth and has several dotted patterns throughout the outer diameter.
The compressive force received by the starwheel's baseplate went through the bottle's wall and the base. The base of the bottles which touch the starwheel's baseplate are the tip of the dotted pattern. The cross-sectional area at that condition is very small and the pressure on the starwheel's baseplate is almost unlimited.

Figure 7. The base part of the bottle

Based on equation (1), the first design has a mass, of 3.7 kg, the second 0.41 kg dan the third design 0.16 kg.

Based on the engineering design by considering the material, dimension and the material cost, the 2nd design was selected. Due to the enough space between the bottle's base and the edges of the plate, this plate design ensures a homogeneous stress distribution around the bottle's base. The geometry of the chosen plate design is shown in Figure 8.

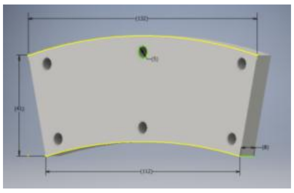

Figure 8. The 2nd design of starwheel's baseplate

Three samples were produced base on the 2nd plate design. As already explained in section 2, the 1st sample was tested without any treatments. The 2nd and 3rd samples were heat treated with different parameter sets. Thereafter, all 3 samples were than tested directly on the automatic filling machine and followed by surface roughness test. The capacity of the automatic filling machine on PT. X is 180 cycles per minute.

Figure 9 shows two indentations (A and B) on the 1st sample (non-heat treatment) after 1,143,477 cycles (± 16 days) tested on the automatic filling machine.

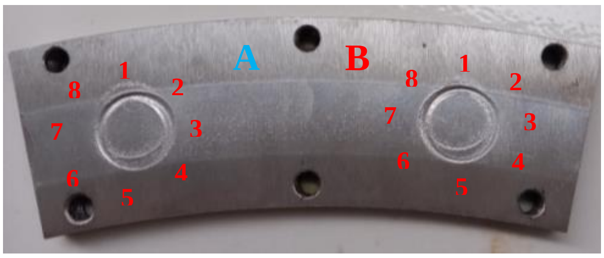

Figure 9. The state of non-heat treated starwheel's baseplate after being tested on the automatic filling machine.

The average surface roughness (R_a) and the maximum depth (R_v) measured at 8 different positions along both indentations on the non-heat treatment starwheel's baseplate are shown in Figure 10 and Figure 11 respectively.

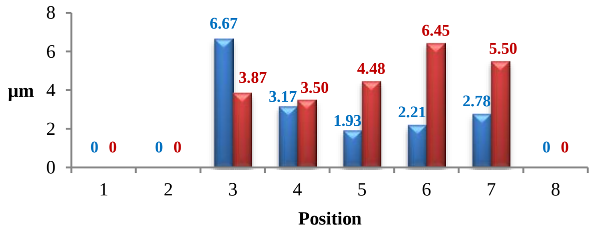

Figure 10. The average surface roughness (R_a) of the non-heat treated starwheel's baseplate

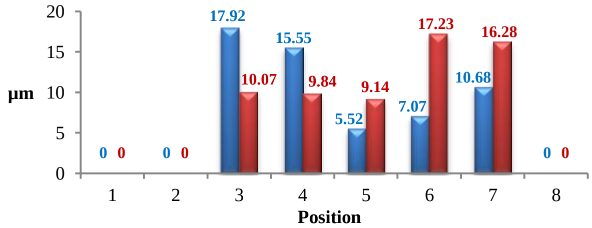

Figure 11. The maximum depth (R_v) of the non-heat treated starwheel's baseplate

From both figures it can be identified that the surface roughness and the depth of the indentations were very large. Even at position 1, 2 and 8 of both indentations, the measurement values were over the limit of the roughness testing device.
The 2nd sample of the starwheel's baseplate was heat treated at austenization temperature of 850 °C followed by tempering at 180 °C as shown in Figure 12.

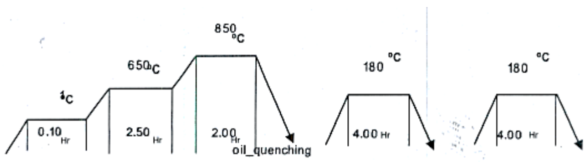

Figure 12. The heat treatment process at austenization temperature of 850 °C followed by tempering at 180 °C

The heat treatment process resulted in an increase of the hardness value of the material from about 13 HRC to 52 HRC. After testing on the automatic filling machine for around 1.1 million cycles (± 16 days), two indentations can be visually recognized as shown in Figure 13. Comparing both samples, the indentations produced on the 2nd samples were much swallower than that on the 1st sample.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 16, Number 3 (2021) pp. 175-180

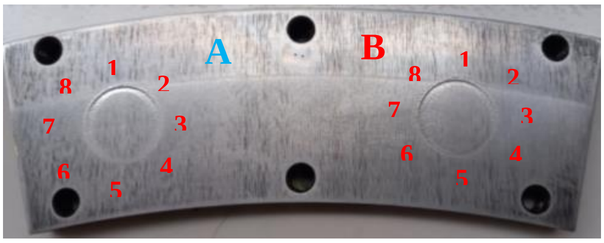

Figure 13. Starwheel's baseplate with a hardness of 52 HRC after tested on an automatic filling machine for about 1.1 million cycles.

Average surface roughness (R_a) and the maximum depth (R_v) of the 2nd starwheel's baseplate is shown in Figure 14 and Figure 15 respectively.

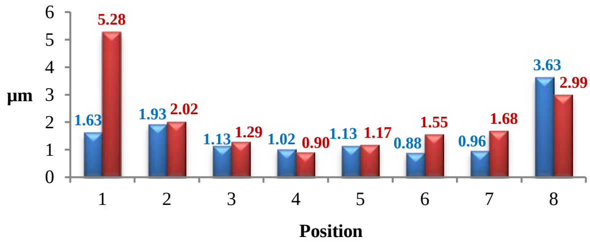

Figure 14. The average surface roughness value (R_a) of the 2nd sample of starwheel's baseplate with a hardness of 52 HRC.

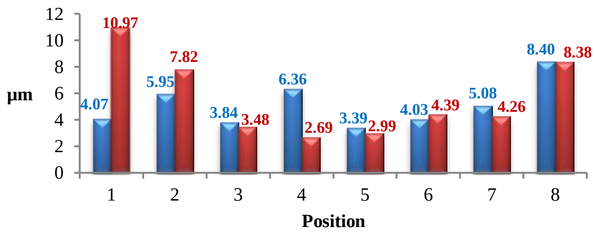

Figure 15. The depth value (R_v) of the 2nd sample of starwheel's baseplate with a hardness of 52 HRC.

Both Figures showed that the average roughness and depth value of the 2nd sample are much lower than those of the non-heat treated material. The maximum average roughness and the maximum depth of the 2nd sample are 5.28 µm and 10.97 µm respectively. Furthermore, the measurement values at all 8 position around the indentations are below the measurement limit of the surface roughness testing device.

The 3rd sample was heat treated at austenization temperature of 850 °C followed by tempering at 600 °C as shown in Figure 16.

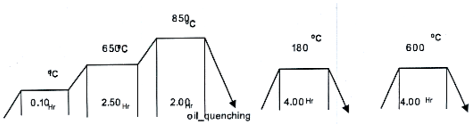

Figure 16. The heat treatment process with austenization temperature at 850 °C and tempering temperature at 600 °C

The hardness value of the material resulted from this heat treatment process (30 HRC) was definitely lower than the hardness value of the 2nd sample. According to these hardness value, the indentations on the 3rd sample after testing on the automatic filling machine for about 1.1 million cycles (± 16 days) seems much deeper than that of the 2nd sample. This can be recognized in Figure 17.

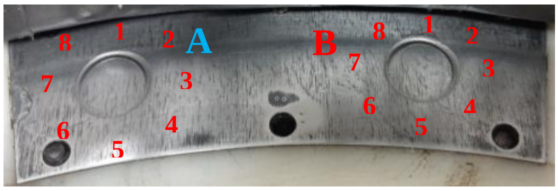

Figure 17. The starwheel's baseplate with 30 HRC hardness condition after tested on automatic filling

Average surface roughness (R_a) and the maximum depth (R_v) of the 3rd sample is shown in Figure 18 and Figure 19 respectively.

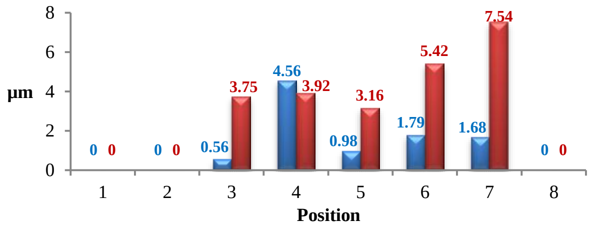

Figure 18. The average surface roughness value (R_a) on 30 HRC starwheel's baseplate

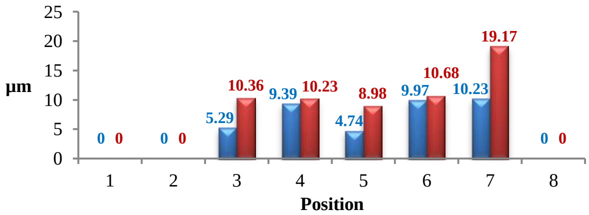

Figure 19. The average maximum depth value (R_v) on 30 HRC starwheel's baseplate

From both Figures it can be recognized that the average surface roughness and the maximum depth of the indentations were not much different than those of the 1st sample (without heat treatment). Like the 1st sample too, the average surface roughness and the depth value of the 3rd at position 1, 2 and 8 were beyond the maximum limit of the roughness testing device.

4. CONCLUSION

From the investigation results it can be concluded that:

a. Based on the test results on an automatic filling machine for ± 1 million cycles and the subsequent roughness tests, the design of starwheel's baseplate carried out by the heat treatment process on the structural material showed better results compared to the previously used starwheel's baseplate.

b. The lifetime of starwheel's baseplate can be increased by heat treating the structural material at an austenizing temperature of 850 ºC and tempering at 180 ºC (hardness value of 52 HRC). Due to this process the production downtime and damaged products can be reduced significantly, which causes an increase in company profits by around Rp. 1 billion - Rp. 2 billion in a month for every automatic filling machine.

c. When testing the starwheel's baseplate on the automatic filling machine, there were no cases of broken bottles during the roll on pressing process and the machine could operate smoothly.

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