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The effect of embossing roll roughness and forming temperature on damage to menthol-coated aluminum foil on packaging

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Abstract
The aims of this study are to determine the effect of embossing roll roughness and forming temperature on the damage of menthol-coated aluminum foil on the packaging, and to determine the best temperature and embossing roll roughness on the quality of the menthol coating on the packaging. In this study, the independent variables were embossed roll wave (roughness level 1000, 500, 0 µm) and menthol foil temperature (22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46°C) to be manipulated, observed, and measured to know the effect with the dependent variable. And because the established variable is the quantity of broken menthol foil packaging that is measured via way of means of calculating the share of period of menthol foil packaging this is torn as compared to the whole period of the foil. Based on the effects of the discussion, it can be concluded that the forming temperature and the embossing roll roughness affect the damage to the menthol packaging layer. In the ANOVA follow-up test, the lowest and best mean value for the forming temperature is at T12 or 44°C, not at T13 or 46°C because at these temperatures the menthol layer on the package is too hot and starts to damage the coating and the lowest and best average for the roughness level of embossed rolls is at E3 with a roughness value of 0 µm (fine).

Keywords:
Roll emboss, forming temperature, foil menthol, packaging.

1 Introduction

In the current era of globalization, competition in the world of work is getting tougher, especially in the industrial sector. Industry competition is competition among or greater comparable or comparable industries to offer products, services, prices, distribution and promotions to customers [1] [2]. In facing this competition, a company is required to increase productivity and quality of production results. So that companies will be able to achieve competitive advantage, namely where a company dominates a business competition arena [2]

One of the leading industries in Indonesia is in the manufacturing sector, for example, the tobacco processing industry because Indonesia is one of the countries that has the most important tobacco commodity within the international. As suggested by the Food and Agriculture Organization, Indonesia is ranked sixth within the international as a manufacturer of tobacco commodities [3]. And has a vital position in using the countrywide economy, as it has a completely extensive multiplier effect, including developing the provider enterprise associated with the availability of commercial enterprise fields and employment, specifically in tobacco-generating areas, cloves and cigarette manufacturing centers. Therefore, the macro role of tobacco commodities and sectors related to tobacco can be seen from the magnitude of changes in output, income, and employment as a response to potential and actual resources to economic changes [1], [4].

Tobacco factories are divided into 4 production plant categories, namely Green Leaf Tobacco (GLT), Dry Ice Expanded Tobacco (DIET), Primary Manufacturing Department (PMD), and Secondary Manufacturing Department (SMD), and based on Top Losses in last year there was a problem in SMD (especially in packer or packaging machine). So the author is interested in taking this theme. Based on the Overall Equipment Effectiveness (OEE) report, which has tracked losses during the production process, it can be concluded that machine downtime and material rejection often occur in packer machines where the embossing roller compaction occurs at <40°C [5] [6] as shown in Fig. 1, which is a fishbone diagram that aims to find the cause of a problem by categorizing Man, Machine, Method, Materials, and Environment (4M1E) [6]–[8].

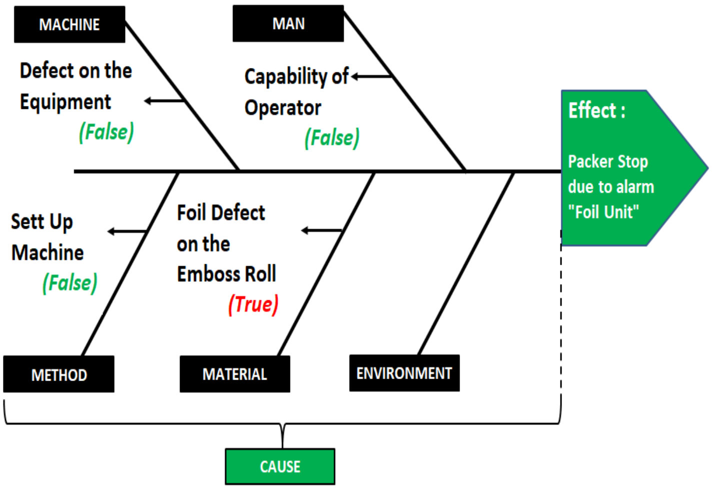

Fig. 1. Fish bone diagram.

After verifying the problem and the potential cause of the problem from the fishbone diagram, it was found that the main cause of the problem is defect foil on roll emboss unit. Then to find the root cause of the problem, it can be used the 5Why tool as shown in Table 1 [9]–[12].

From Table 1, it takes two actions to solve the problem namely making a menthol foil heater and redesigning a new roll emboss that needs to be fabricated and installed on the machine. Research on the topic of menthol was conducted from the conclusion of this research, it was concluded that the melting point of menthol is at a minimum temperature of 42°C [5] [13]. In addition, Jaya Gade, et al. (2017) also conducted research on the topic of the melting point of menthol with the title extraction of menthol using different methods from peppermint oil. And the research results conclude that the melting point of menthol is between 42°C-43°C [14].

Furthermore, in the identical year, Andreasson Eskil, et al. (2017) additionally performed studies on the subject of the energy of aluminum foil in business packaging with the title simulation of skinny aluminum foil inside the packaging industry. It concluded that the identical object 10 µm aluminum foil at room temperature 23°C with the forming course and tensile take a look at with inside the rolling course (rolling direction), the transverse course (transverse direction), and the 45° course, it determined that the energy of aluminum foil become lowest whilst pulled with a role of 45° [7] as proven in Fig. 2 [6].

Based on Fig. 2, it can be described the difference in values between Rolling Direction (RD), Transversal Direction (TD), and 45 when the tensile test is carried out as shown in Table 2.

Table 1. Root cause analysis using 5 why

What	W1	W2	W3	W4	W5	Action Plan
Defect foil on the roll emboss	Foil stuck in emboss unit	Hardened foil material	Crystallization occurred on the menthol foil	The Menthol foil material is not suitable for cold room temperatures	Menthol material is suitable at 40°C	Make a menthol foil heater
		Foil defect when passing roll emboss	The emboss roll design is too rough			Redesign and make a new embossed roll

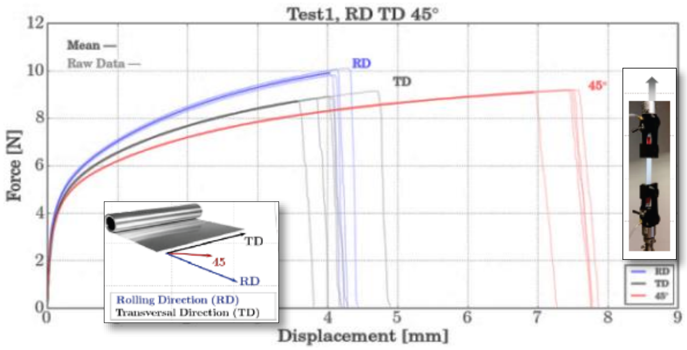

Fig. 2. Mechanical characteristic test results from testing material in-plane mechanical thin aluminum foil material [6].

Table 2. Mechanical material parameters used as input for numerical material models [7]

Direction	Angle α (°)	E (GPa)	σ_a (MPa)	σ_{uts} (MPa)	ϵ_{uts} (%)	Wt (J/mm^3)
RD	0	35.74±5.41	40.66±0.55	74.41	4.14±0.09	2.55
TD	90	35.06±3.50	38.23±0.21	65.76	4.03±0.38	2.14
45	45	32.67±1.99	36.91±0.31	67.96	7.36±0.22	4.38

If E is strain hardening modulus, σ_{uts} is tensile strength, ϵ_{uts} is tensile strain at break, and Wt is tensile energy absorption, then the properties of aluminum foil can be shown in Fig. 3 [6] [15] [16].

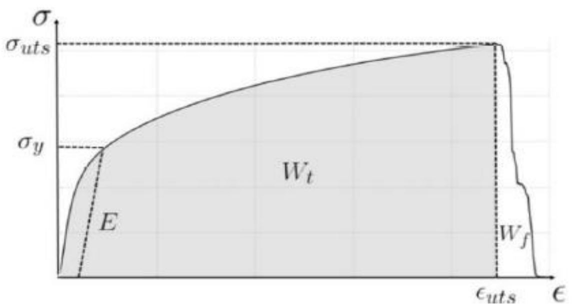

Fig. 3. Definition of material parameters extracted from experimental testing [6].

The material directions RD and TD are extended to the same maximum displacement, whereas the maximum displacement in the 45 direction is nearly doubled. This may be due to the orientation and texture of the crystals in the manufacturing process, namely rolling. Furthermore, the 45° path indicates the bottom mechanical strength of all of the examined object orientations. The experimental take look at the curve may be parameterized with analytical expressions. Furthermore, the object version may be calibrated analytically with the Eq. 1 [6] [17].

$$\mathcal{E}(\sigma) = \mathcal{E}e + \mathcal{E}p = \sigma/E + (\sigma 0/E0)\ N \qquad (1)$$

Where E is the tensile modulus, which may be received without delay from the preliminary slope of the measurement, E_0 means stress-strain modulus (Eq. 4) and N means stress hardening exponent (Eq. 3). Parameters E_0 and N can be obtained analytically from the parameterization values. Using the values for the pressure at destroy and the tensile power within the Ramberg-Osgood system we have [6] (Eq. 2).

$$\mathcal{E}_{uts} = \frac{\sigma\ uts}{E} + \left(\frac{\sigma\ uts}{E_0}\right)^N \qquad (2)$$

$$N = \frac{\sigma\ uts^2 - 2EWT}{\sigma\ uts^2 + 2E(WT - \sigma_{\ uts}\ \mathcal{E}_{uts})} \qquad (3)$$

$$E_0 = \frac{\sigma\ uts}{\left(\mathcal{E}_{uts} - \left(\frac{\sigma\ uts}{E}\right)\right)^{1/N}} \qquad (4)$$

Where at Eq. 2, Eq. 3, and Eq. 4 σ_{uts} is tensile strength, $\mathcal{E}_{uts}$ is the tensile strain at break, and WT stands for tensile energy absorption. All the inputs had to calculate the expression may be received from a general experimental tensile test, so that is an instance of the direct method, after which the shear modulus may be calculated the usage of the subsequent equation as proven in Eq. 5.

$$G_{RDTD} = \frac{1}{\left(\frac{4}{E45} + \left(\frac{2VRTD}{ERD}\right) - \left(\frac{1}{ERD}\right) - \left(\frac{1}{ETD}\right)\right)} \qquad (5)$$

Research on the topic of menthol foil was also carried out by Cooperation Center for Scientific Research Relative to Tobacco in 2019 with the title determination of menthol in cigarettes and cut filler with gas chromatography. This experimental study utilized gas chromatography to determine the menthol content in cigarette filters with a prototype cigarette type value of 2 mg/cig, and a commercial type of min 3 mg/cig [18]–[20].

2 Research Methods

2.1 The Research Flow Chart

The research flow chart during the process is shown in Fig. 4.

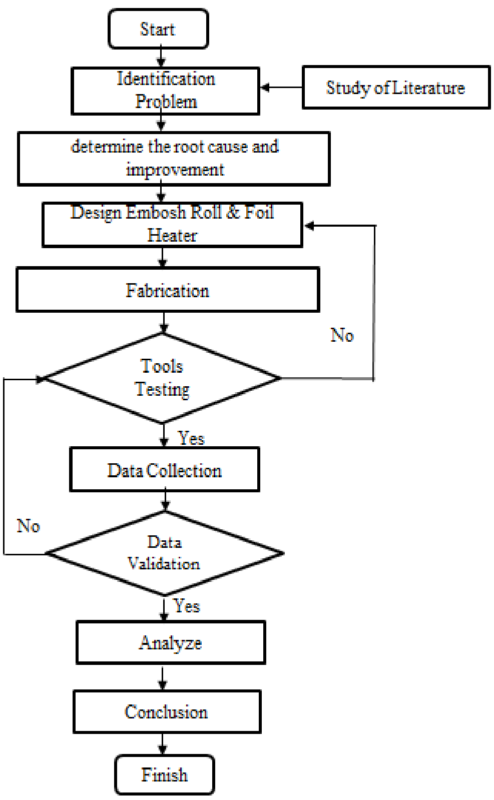

Fig. 4. Research flow chart.

2.2 The Experimental Variables

In this observation, the impartial variables had been emboss roll wave (roughness level 1000, 500, 0 µm) and menthol foil temperature (22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46°C) to be manipulated, observed, and measured to know the effect with the dependent variable. The dependent variable is the amount of damaged menthol foil packaging which is measured by calculating the percentage of length of menthol foil packaging that is torn compared to the total length of the foil, to evaluate the results of the manipulation of the independent variable.

The preparation of tools and materials is the fabrication of the roll emboss, manufacturing of the forming temperature control device, and preparation of the foil material to be installed on the production machine. Only 1 unit is made to control the forming temperature, but it can be adjusted the temperature by changing the distance between the heater and the material. As for the emboss roll, it was made in 3 conditions, namely coarse (1000 µm), coarse (500 µm), and fine (0 µm) as shown in Fig. 5.

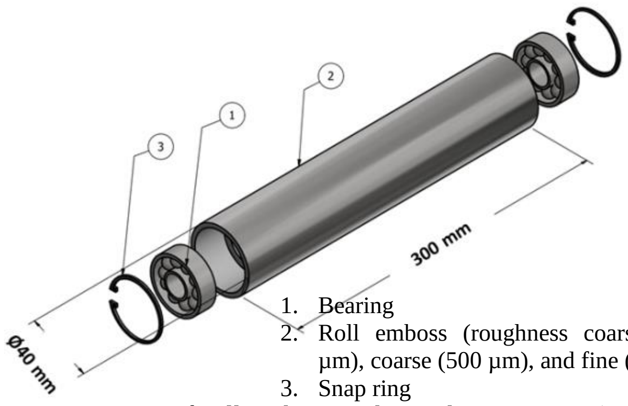

Fig. 5. Design of roll emboss with roughness coarse (1000 µm), coarse (500 µm), and fine (0 µm).

Then to adjust the surface temperature of the aluminum foil, a heater is required using a ceramic heater with an additional adjuster to adjust the exposure distance between the heater and the surface of the aluminum foil as shown in Fig. 6.

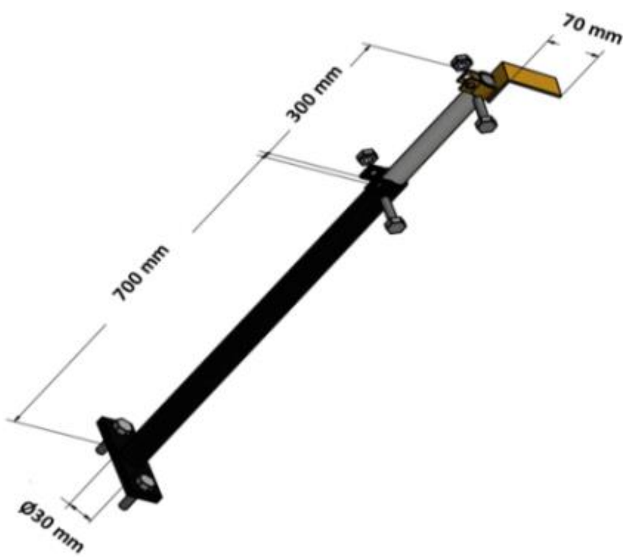

Fig. 6. Design of ceramic heater with adjuster.

2.3 The Experimental Procedures

After the roll emboss and ceramic heater with adjuster have been fabricated, they can be installed on the packer machine for further trial and data collection as shown in Fig. 7.

During production, damage data on aluminum foil is recorded and the length of the damaged foil is measured and compared to the total length of the material used during the production process as shown in Fig. 8.

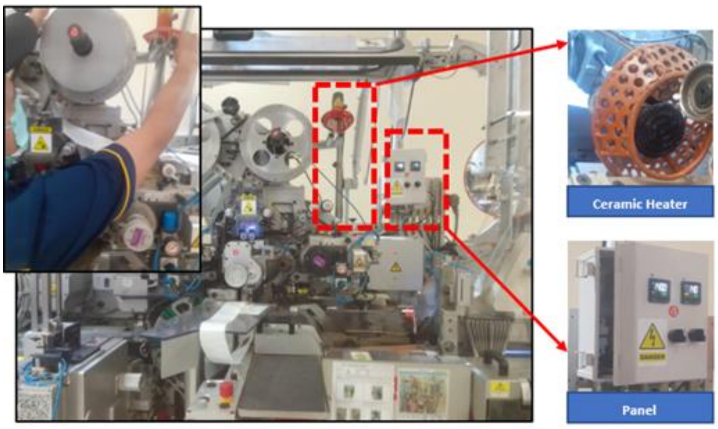

Fig. 7. Process installation of roll emboss and ceramic heater with adjuster.

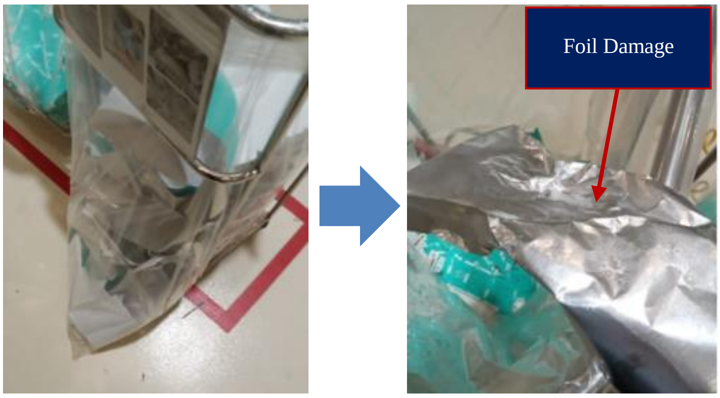

Fig. 8. Measurement process of damage percentage.

2.4 Damage Characteristics of Menthol Coating of the Packaging

In the manufacturing industry, some terms or guidelines are used to classify production process waste which is divided into 7 waste categories, namely waste of overproduction, waste of inventory, waste of defects, waste of transportation, waste of motion, waste of waiting, waste of over processing [21].

In the case of this research, the damage to the menthol layer of the packaging is a category of waste of defects in the material during the cigarette packaging manufacturing process which is affected by the embossing roller and the forming temperature, resulting in tearing of the material which can be seen with the eyes (manual inspection).

3 Results and Discussions

In some conditions, the independent variable will take the results of the dependent variable with a combination of the machine's built-in system that records every problem foil alarm that occurs while the engine is running on the machine's HMI which is displayed in the form of frequency and duration numbers, as well as manual descriptions by researchers for the classification of torn and damaged materials by making material inspection standards. So, when recording the dependent variable data that is used as a measure is to calculate the percentage of damaged foil length (m) compared to the total length of foil material in each 1 roll (1500 m), not minutes, because the tear duration unit is highly dependent on the operator's ability to solve machine problems and each operator, has ensured that his competency is the same as the skill matrix assessment as shown in Fig. 10, so that the ability of the operator is not a cause. The percentage of damaged foil can be calculated by dividing the length of the damaged foil by the total length of the foil and converting to a percent multiplied by 100% as shown in Eq. 6.

$$\%Foil\ defect = \frac{Damaged\ foil\ lenght}{Total\ length\ of\ foil} \times 100\% \qquad (6)$$

During the production process, the Integrated Working System (IWS) was implemented, one of the pillars of which is autonomous maintenance which has tools for monitoring that the system is running, namely centerline (machine standard settings to ensure stable machine output and performance with different operators), CIL (Cleaning Inspection and Lubrication to ensure the machine is maintained by the same method with different operators), and defect handling (standard for finding abnormality of every machine problem) as shown in Fig. 9 [22].

Fig. 9. Autonomous maintenance pillar in IWS system.

Then to ensure that the system is already implemented, a skill assessment is carried out once a month for 3 operators (operator A, operator B, and operator C) with an assessment score system is "1" (lack of knowledge because they have not been trained), "2" (already received training, but needs assistance), "3" (can do independently), "4" (can do independently and can teach other operators), and "5" (can do independently, teach other operators, and can make improvements). The skill assessment scores of the 3 operators have met the target and can be seen in Fig. 10 [22].

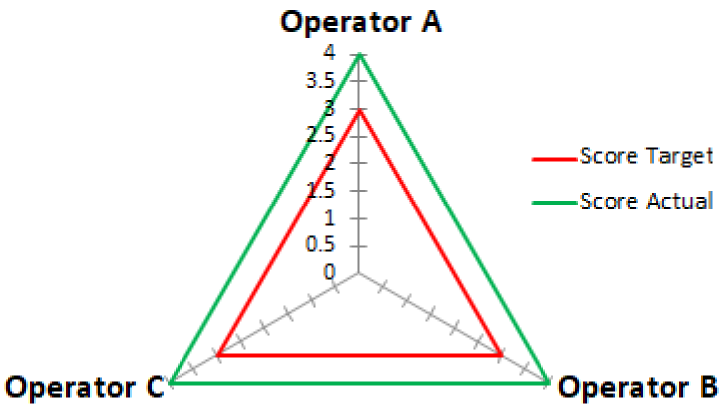

Fig. 10. Operator skill assessment score.

So from Fig. 9 and Fig. 10, it can be concluded that operators already have the same capability and henceforth the data retrieval process can be carried out using experimental methods.

Table 3 shows after the data collection and validation stages were completed, in this experimental research the data testing phase was carried out with the Factorial ANOVA Test using Minitab software by grouping the results of data collection with symbols T1 to T13, which represent different temperature conditions, and E1 to E3, which represent the level of emboss roughness.

Table 3. Data of independent and dependent variable

Temperature		Distance	Type of roll emboss (μm)		
°C	T	cm	Coarse (1000 μm)	Coarse (500 μm)	Fine (0 μm)
22°C	T1	102	0.38%	0.32%	0.21%
24°C	T2	90	0.38%	0.33%	0.20%
26°C	T3	70	0.38%	0.33%	0.20%
28°C	T4	60	0.38%	0.33%	0.20%
30°C	T5	40	0.38%	0.28%	0.20%
32°C	T6	35	0.38%	0.28%	0.20%
34°C	T7	33	0.37%	0.28%	0.15%
36°C	T8	30	0.37%	0.27%	0.12%
38°C	T9	27	0.36%	0.26%	0.11%
40°C	T10	23	0.35%	0.26%	0.10%
42°C	T11	20	0.35%	0.24%	0.10%
44°C	T12	18	0.35%	0.21%	0.08%
46°C	T13	16	0.35%	0.22%	0.08%

Fig. 11 shows the results of the ANOVA advanced test to determine the best forming temperature. The mean value that appears in the results of the ANOVA test is the percentage value of damage resulting from each different temperature, so the lower the mean value, the better. So, in Fig. 11 the lowest and best mean value is at T12, which is at a temperature of 44°C, not at T13 or a temperature of 46°C because at that temperature the menthol layer of the packaging is too hot, and beginning damage the coating [23].

Fig. 12 shows the results of the ANOVA advanced test to determine the best-embossed roll roughness. The mean value that appears in the results of the ANOVA test is the percentage value of the damage resulting from each different embossed roller roughness value, so the lower the mean value, the better. So, in Fig. 11 the lowest and best mean value is at E3, namely at a roughness value of 0 μm (fine).

Fisher Pairwise Comparisons: Faktor T

Grouping Information Using Fisher LSD Method and 95% Confidence

Faktor T	N	Mean	Grouping
T1	6	0.0030038	A
T2	6	0.0029883	A
T3	6	0.0029788	A
T4	6	0.0029676	A
T6	6	0.0028490	B
T5	6	0.0028254	B
T7	6	0.0026860	C
T8	6	0.0025515	D
T9	6	0.0024685	E
T10	6	0.0023870	F
T11	6	0.0023028	G
T13	6	0.0021654	H
T12	6	0.0021181	H

Means that do not share a letter are significantly different.

Fig. 11. ANOVA advance test results for forming temperature.

Grouping Information Using Fisher LSD Method and 95% Confidence

Faktor E	N	Mean	Grouping
E1	26	0.0036635	A
E2	26	0.0027650	B
E3	26	0.0014852	C

Means that do not share a letter are significantly different.

Fig. 12. ANOVA advance test results for roughness of roll emboss.

The results of the ANOVA test can be described as shown in Fig. 13 which visualizes the percentage of damage on aluminum foil from the independent variables, the roughness of the roll emboss and the forming temperature.

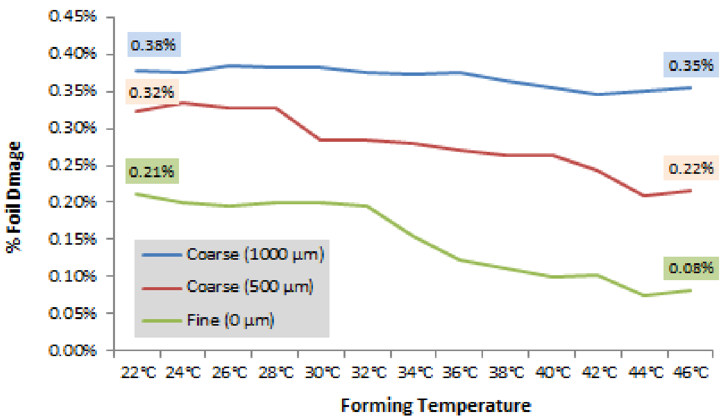

Fig. 13. Percentage of damage vs. roughness roll emboss and forming temperature.

Fig. 13 explains that the X axis is forming temperature, the Y axis is % foil damage, and the emboss roll roughness is represented by green line (E3), red line (E2), and blue line (E1). The green line with a temperature of 44°C (T12) is the best condition due to the lowest percentage of foil damage.

4 Conclusion

Based on the consequences of the dialogue it can be concluded 1) the forming temperature has an impact on the harm to the menthol coating of the packaging, 2) the level of roughness of the embossed roller affect the damage to the menthol packaging layer, 3) in the advanced ANOVA test, it was found that the lowest and best mean value for the forming temperature was at T12, namely at 44°C, not at T13 or 46°C because at that temperature the menthol layer of the packaging was too hot and started to damage the coating, 4) in the advanced ANOVA test, it was found that the mean value was the lowest and the best for the roughness level of the embossed roll at E3, namely at a roughness value of 0 µm (fine).

Acknowledgment

To add references for further research, there are several suggestions put forward 1) further research to obtain more accurate and real-time data needs to create an automatic temperature control device that can go up and down automatically to adjust the surface of the object being heated, 2) include variables that have not been examined in this study which can be used for research improvement.

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