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RESEARCH ARTICLE

Root cause analysis for warming delay of resilient solid tire heel compound during manufacturing

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ABSTRACT

Warming of rubber compounds is carried out using warming mills to improve the processability of the tyre compounds before production. Delaying warming process causes production losses in several terms. Therefore, an experiment was set up to study the root causes for the warming delay that occurs when warming solid tyre heel compounds in warming mills. Brainstorming sessions were used and the maturity of the heel compounds and nip size of warming mill were identified as the main causes for the warming delay. The maturity time of the heel compounds varied as 6, 12, 24, and 48 h while the nip size of the mill varied from 7 to 10 mm at 1 mm intervals. The results of the two-way ANOVA highlighted that there was an interaction between maturity time and nip size on warming delay. Overall, the warming time can be reduced to 6 minutes; which was 8 to 10 minutes previously when using 9 mm nip size in the warming mill and maturing of the compound for 48 h.

***Keywords**: Nip size, solid tyre heel, warming delay*

INTRODUCTION

Solid tyres are especially used in heavy-duty applications such as heavy trucks, military vehicles, construction machineries, trailers etc. (Phromjan and Suvanjumrat, 2018). Therefore, its safety endurance and economical features greatly exceed that of other tyres. There are mainly three types of solid tyres in the market. They are press-on tyres, resilient tyres, and non-marking tyres (Sri Lanka Export Development Board, n.d). Among these, carbon black reinforced resilient type solid tyres are widely used in industrial applications as mentioned above while press-on tyres are used in forklifts and trolleys and non-marking tyres are used in forklifts in food processing factories, hospitals and pharmaceutical industries etc. (Wood, 2018). These resilient type solid tyres consist of three distinct components namely tread, cushion, and heel/base (Rangdale *et al.,* 2018). Tread, which touches the road, is designed to have high abrasion resistance, high resilience, low heat build-up, good tear strength, and resistance to general ageing (Srivastava and Bhuyan, 2018). The cushion (the middle layer of the tyre) consists of properties such as high elasticity, high resilience and low heat build-up which ensure the comfortability of the tyres. The most inner component which fits the tyre to the vehicle via rim is called the heel component. It is designed to have sufficient grip on the rim. The heel accommodates tension members that consist of steel bead wires to maintain dimensional stability under heavy loads (Zhang and Tang, 2001).

Tyre manufacturing is a complicated multi-step process that involves various types of materials and processing steps (Srivastava and Bhuyan, 2018). It initiates from inspection of raw material and finishes from the grading of the tyres and aftercare of usage (Gupta *et al.,* 2018). The compounds used for the heel are different from other components of the resilient type solid tyres. The preparation of rubber compounds for solid tyres is a key function of the manufacturing process since it affects the whole properties, performance, and life of the tyre. Rubber compounds used in the heel are prepared in big volumes and keep as piles until used in the tyre building process. During this time, the compounds are maintained at room temperature and allowed to mature. However, the properties of the compound such as viscosity and processability are changed with time. Before compounds come to the subsequent step, the warming stage, compounds are stored at the storing houses for two days normally. But, sometimes the maturing time is less than two days.

After that, the compounds are taken for the next processing stage where warming up of compounds is done. There, warming mills are used and compounds are warmed according to a pre-specified time limit which is normally 4-8 minutes. While the heel compound is warming it tends to take more time of 8-10 minutes than the pre-specified limits. This exceeded time limit is termed as 'warming delay' and it influences negatively the total production efficiency of tyres. Long (1985) has observed similar observations in styrene butadiene rubber (SBR) based compounds once processed. The higher molecular weight and the narrower molecular weight distribution of SBR were found as the reason for this delay. However, Tokita (1979) has suggested that the warming delay on the mills can be reduced or eliminated by making the proper adjustments for the mill's nip distance, mill surface temperatures, and/or friction ratio. When facing such challenging issues, usually it relies on brainstorming sessions (Ritterand and Mostert, 2018) to have ideas that could be used to solve such issues (Haberberg and Rieple, 2008). Therefore, the objective of this study was to investigate the causes for the warming delay of resilient solid tyre heel compound of warming mill during manufacturing.

MATERIALS AND METHODS

Materials

Resilient solid tire heel compounds were taken from the central mixing plant of the company and two roll mill (XK-560C model) was used to warm the compounds. The maturation time of the compound was identified using the compound's identity label.

Identification the possible causes by a brainstorming session

A brainstorming session was conducted with the twelve expertise persons of the company representing the quality assurance, industrial engineering, maintenance and production departments. At the beginning of brainstorming session, the goals of the session and the outline of the brainstorming process were given to the participants. Twenty minutes were allocated for the participants to write the possible causes for the warming delay of the heel compound of solid tyre. After getting all responses from the individual participants, the questionnaire was prepared including all mentioned possible causes such as high viscosity value of the compound, high thickness value of the incoming compound sheets, high lowest torque (ML) value of the compound, the variation of the mill nip size, maturity level (in days) of the compounding ingredients, low heat absorbance capacity of the compound, poor dispersion of compound, low warming mill temperature, low warming mill speed, improper working of the cooling system of the warming mill, loading high quantity of compound to the mill bank than the specified limit, high amount of fiber content, low compound mixing cycle time, less rubber percentage in the compound, use of the compound in rainy days, poor working skills of the warming mill operator. To select the most possible causes, each participant was asked to score for the identified questions from 1 to 3 where, one (01) mark for having less possibility to be a root cause, two (02) marks for causes that are having a moderate impact and three (03) marks for the most significant causes. Finally, all marks were weighted to find the most significant causes for the warming delay. The two major root causes were selected for further experimental studies.

Determination of the effect of nip size of the warming mill and the maturation time of the heel compounds

The best maturation time of the compound and the nip size of the warming mill which could reduce the warming delay of the heel compounds were investigated using sixteen treatment combinations (Table 1). Thirty (30) random samples were collected for each treatment (including three replicates, with ten samples per replicate).

Table 1: Treatment combinations of nip size and maturation time.

Treatment	Nip size (millimetre)			
Maturation time (h)	7	8	9	10
06	0706	0806	0906	1006
12	0712	0812	0912	1012
24	0724	0824	0924	1024
48	0748	0848	0948	1048

*Note – sample code is given in the table, i.e. 0706 represents the sample matured for 6 h and milled using 7 mm nip size.

RESULTS AND DISCUSSION

Selection of possible causes from brainstorming

From the results of the brainstorming session, sixteen possible causes were identified. They are high viscosity value of the compound, high thickness value of the incoming compound sheets, high ML (lowest torque) value of the compound, the variation of the mill nip size, the maturity level of the heel compound, low heat absorbance capacity of the compound, poor dispersion of compound, low warming mill temperature, low warming mill speed, improper working of the cooling system of the warming mill, loading high quantity of compound to the mill bank than the specification limit, high amount of fiber content, low compound mixing cycle time, less rubber percentage in the compound, use of the compound in rainy days, and poor working skills of the warming mill operators. Table 2 represents the results of the identified causes and the score of each cause. According to Table 2, the nip size of the warming mill and the maturity level of the heel compound were selected as those two factors have got the highest weightage from the assigned scores.

Table 2: Results of the brainstorming session.

No:	Causes	Marks	Rank
1	Maturity level of the compound	35	1
2	Variation of the mill nip size	34	2
3	High thickness value of the incoming compound sheets	31	3
4	High viscosity value of the compound	30	4
5	High ML value of the compound	29	5
6	Low compound mixing cycle time	26	6
7	Less rubber percentage in the compound	24	7
8	Poor dispersion of compound	23	8
9	High amount of fiber content	23	8
10	Loading high quantity of compound to the mill bank than the specified limit	21	10
11	Low heat absorbance capacity of the compound	20	11
12	Improper working of the cooling system of the warming mill	18	12
13	Use of compound in rainy days	16	13
14	Low warming mill temperature	15	14
15	Low warming mill speed	14	15
16	Poor working skills of warming mill operator	14	15

The Ishikawa diagram (Figure 1) shows all the relevant causes for the warming delay of the solid tyre heel compounds.

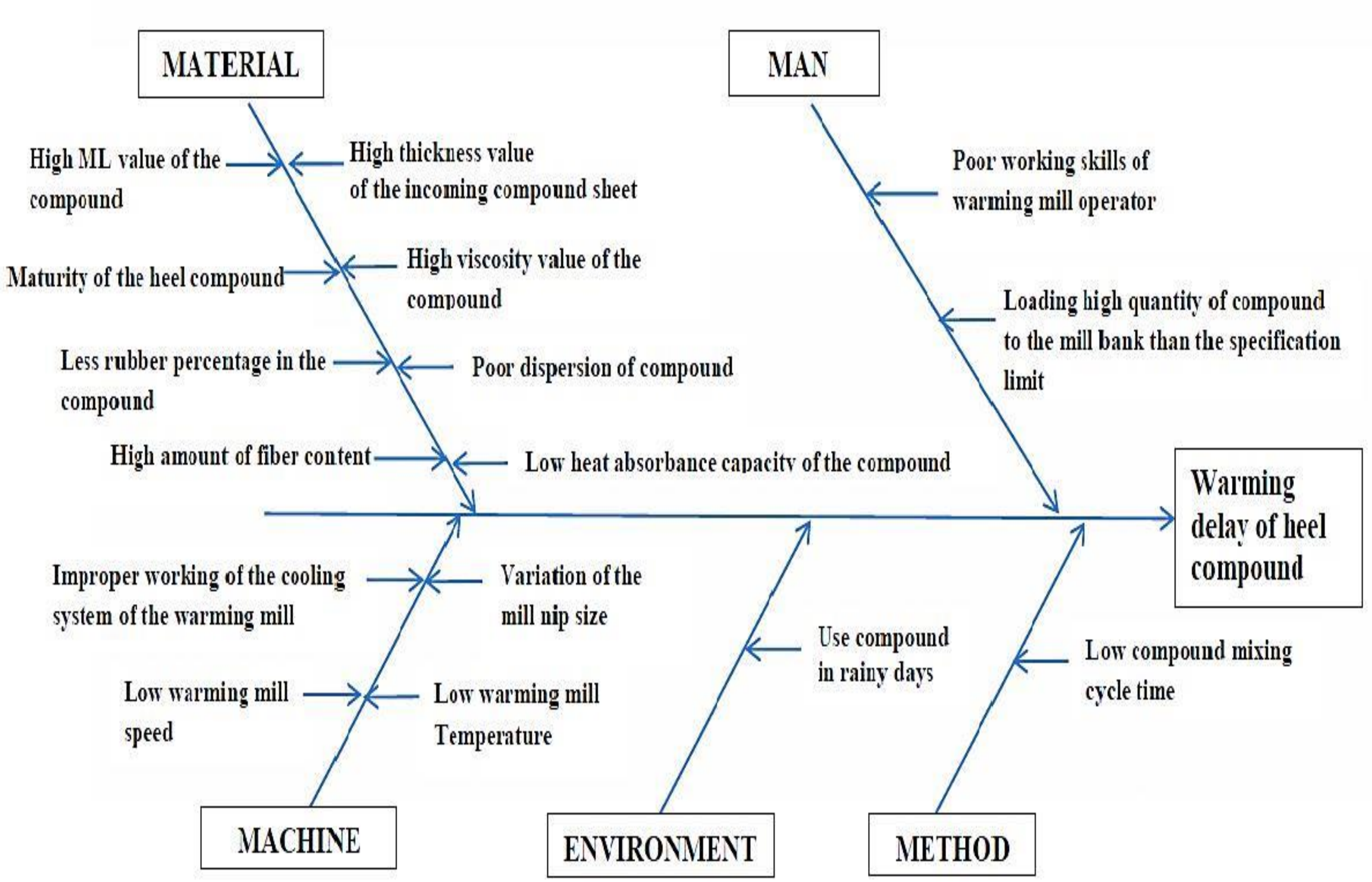

Figure 1: Ishikawa diagram of possible causes for warming delay.

Effect of maturation time and nip size on warming delay

Tukey pairwise comparisons were carried out to group the treatments at 95% confidence. According to Tukey pairwise; treatments were grouped into sixteen groups. Figure 2 represents the variation of warming delay of heel compound. Results revealed that treatment 0948 which includes nip size 9 mm and maturity hours 48 had the lowest warming time. The treatment 0924 had the second-best lowest warming time. Also, there was a significant difference between treatment 0706 & 0806, 0812 & 0912, 0924 & 0948. The specification limit of the warming was 4-8 minutes. Except for the treatment 0706 (nip size 7, maturation time 6), all the other treatments showed warming time above the limit.

The warming delay reduced when the nip size is increased from 7 to 9 mm and also the warming delay increased once the nip size increased beyond 9 mm. The reason for the reduction of warming delay can be attributed to the relationship between the changing of nip size and the shear force as evident by Broadbent *et al.* (1978). According to their study, it has found that the torque of the mill decreases with increasing the nip size as well as the higher torques lead to a higher shear force in the two roll mill; thereby it decreases the warming delay. When the nip size was reduced up to 7 mm, with the high shear force the compound tend to crack into smaller pieces without making a continuous sheet. Hence, the compound will not get warmed.

However, with the nip size of 10 mm, as the nip size is increased, the torque remains reasonably constant (Broadbent *et al.*, 1978) and the rubber compound will get bagging. That could be the reason for further increase in the warming delay after nine minutes. Moreover, if the compounds are matured for 48 h there is a possibility to reduce the warming delay at all the nip sizes. Also, the lowest warming delay of compounds can be achieved if the nip size of the mill is adjusted to 9 mm at all the maturation times. Therefore, there is a possibility to adjust the warming delay of the heel compounds by varying the nip size of the warming mill and the maturation times of compounds.

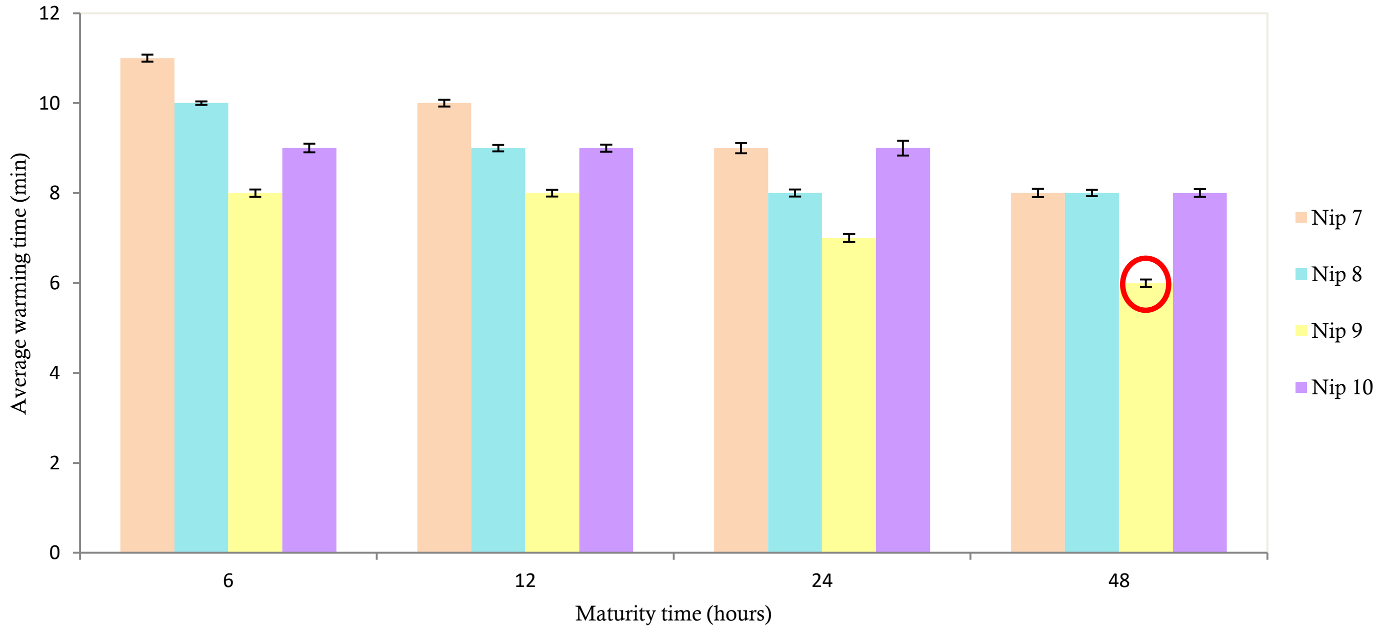

Figure 2: Variation of warming delay of heel compounds with maturation time at different nip size.

CONCLUSIONS

Several factors can affect the warming delay of the solid tire heel compound. But, the warming delay of such compound can be reduced or eliminated by varying the nip size of the warming mill as well as the maturity level of the compound. Overall, the warming time can be reduced to 6 minutes which was 8 to 10 minutes previously, using 9 mm nip size in the warming mill and maturing the compound for 48 h. In conclusion, if the nip size of the warming mill is kept at 9 mm, it is possible to significantly reduce the warming delay of heel compounds to 6-8 minutes at all maturation times; which could increase the production efficiency of the solid tyre production process.

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