The effects of screw rotation speed on viscosity, mooney scorch time and dieswell of hot-feed blending rubber-compound prepared by gs/w 250 extruder machine

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Abstract. This paper is an experimental study that aimed at figuring out the effect of screw rotation speed on the viscosity, mooney scorch time and dieswell of rubber-compound blending prepared by GS/w 250 Extruder Machine to determine the appropriate parameter setting for the expected rubber-compound specification. The screw rotation speed was set at 10, 20, 40 RPM and the three-zone temperature of the screw extruder was set by the TCU. Viscosity and Mooney Scorch Time (MST) of rubber-compound were evaluated before and after extruding process using the Mooney Viscometer test equipment. The Die Swell of the rubber-compound were evaluated after blending process using the dynamic rubber process analyzer. The result showed that the Viscosity and Mooney Scorch Time of rubber-compound before extruder process was around 56.59 mooney and 19.69 minute. After extruding process, the value of Mooney Viscosity was consecutively around 51.55, 51.25, 50.55 mooney and the value of Die Swell was consecutively around 0.493, 0.536, 0.553Lb-in. The value of Mooney Scorch Time was consecutively around 19.00, 15.47, 17.37 minute. The results indicates that, the increase of screw rotation speed decrease the Viscosity and increase the Die Swell of the rubber-compound.

1. Introduction
The consumption of polymer have been widely used in rubber industry. Polymer has mechanical and thermal properties of interest. Several polymer have ductile and resistant to acid, but will be swelling when in contact with gasoline, oil or grease. Therefore, for special application such as tyre its toughness is not sufficient. The strength of a polymer can be considerably improved by blending in a rubber [1-8]. This blends can be made in a reactor process on an extruder [9].This blends produce very ductile materials, commonly called rubber-compound. The extruder is arguably the single most important piece of polymer processing machinery [10,11]. The extrusion process are controlled by setting barrel temperatures and screw rotation speed [12].

The effects of screw rotation speed on extruding process has been studied extensively. One study focussed on HDPE rheology in a given condition whose result reflected the dependency of the variation in radial melt temperatures on screw rotation speed, and polymer viscosity [13]. Other studied the effect of screw speed on the quality of devulcanized rubber whose result showed that the screw speed affects the percent of devulcanization, especially at low and middle levels of barrel temperature. So, with the increase of screw speed devulcanization process becomes more efficient [14]. There are three correlated method in evaluating rubber-compound. Mooney Viscosity, Mooney Scorch time, and die swell. Mooney Viscosity test is the most popular test method to evaluate the character
polymers and rubber materials. Rubber-compound viscosity plays vital role in deciding its processing behaviour, whereas the deviation in viscosity will critically alter its processibility such as in calendering, extruding or injection moulding. So, it is necessary that viscosity parameter be maintained within specified limits. The second one, Mooney Scorch, is one of the most useful tests to determine starting of cure of rubber-compounds known as scorching behavior, providing essential data for designing and controlling production processes as well as checking material consistency. It indicates how long a rubber-compound can remain warm for processing before it loses its ability to change its shape. Often once a rubber-compound is scorched, it can no longer be processed. Therefore, it is important to measure the scorch time and adjust it based on the processing conditions. In a quality control environment, evaluating the scorch time ensures that no time is wasted processing or molding material that will not create a good product for premature scorch can lead to underfilled mold cavities as the material loses its ability to flow before completely filling the space. The last one is die swell test. Die swell occurs when an extrudate has larger diameter than die [10]. It is an important parameter for characterization of elastic properties during extrusion of polymer melts, and the degree of swell degree is usually expressed by die-swell ratio [15]. The measurement of die swell is best as a qualitative measure of the flow behavior [16].

Several rubber-compound processing will be change its characteristic. Therefore, the tests mentioned before has to be done to evaluate of rubber-compound characteristic in order to ensure consistency quality of the finished goods. Based on that reason, this paper studied the effects of screw rotation speed on viscosuity, mooney scorch time and dieswell of rubber-compound using hot-feed Extruder Machine.

2. Materials, Extruder Machine, Measurement Test Equipment and Experimental Processes

Material, apparatus and experimental processes will be explained below:

2.1. Materials

The materials used in this experiment was hot-feed rubber-compound whose composition is shown in Table 1.

| Material | Kategori       | Formulation (phr) |
|----------|----------------|-------------------|
| MR-01    | Natural Rubber | 75                |
| BR-1220  | Polimer Rubber | 15                |
| SBR-1502 | Polimer Rubber | 10                |
| HISIL 225| Silica         | 15                |
| N-234    | Carbon Black   | 40                |
| X-50 S   | Coupling Agent | 3                 |

2.2. Extruder Machine

A co-rotating single-screw extruder (Model No. GS/w 250, TROESTER GmbH & Co. KG., Am Brabrinke 1-4 Hannover, GERMANY) was used in this study. The extruder’s screw diameter is 250 mm with an L/D ratio of 8.

2.3. Measurement Test Equipment

Refering to ASTM D1646, a mooney Viskometer (Model Ektron EKT-2003M) was used to measure the viscosity and mooney scorch time test before and after extruding process. In evaluating the die swell, based on ASTM D6601, the Dynamic Rubber Process Analyzer (Model Mon Tech D-RPA 3000) was used.

2.4. Experimental Process

The preheating extruding process was used in order to produce hot-feed rubber-compound which was then used to feed the experimented extruding machine. Hot-feed compound then entered the barrel
whose temperature was set in three zones: feed (80°C), compression (70°C) and metering (80°C). The screw rotation speed variations were: 10, 20 and 40 rpm delivered the compound to the head extruder. The viscosity, mooney scorch and dieswell testing were done to test the rubber-compound.

3. Result and Discussion
The experimental result is as follow:

3.1. Mooney Viscosity
The Viscosity of hot-feed rubber-compound before extruding process was around 56.59 mooney. The viscosity of rubber-compound was affected by screw rotating speed as is shown by figure 1.

![Figure 1. The effect screw rotating speed on viscosity of rubber-compound](image1)

Figure 1 above shows that the minimum screw rotating speed was at 10 rpm, the viscosity was 51.55 mooney. When the maximum speed was applied (at 40 rpm), the viscosity changed to 50.55 mooney. It shows that the increase of screw rotation speed will decrease the viscosity of rubber-compound.

3.2. Mooney Scorch Time
The Mooney scorch time of hot-feed rubber-compound before extruding process was around 19.69 minute. The mooney scorch time after extruding process with screw rotating speed variation is shown in figure 2.

![Figure 2. The effect screw rotating speed on mooney scorch time of rubber-compound](image2)
Figure 2 above shows that the minimum value of mooney scorch time is 15.47 minute when the screw rotating speed was at 20 rpm, and the maximum value of mooney scorch time is 19.00 minute when the screw rotating speed was at 10 rpm. It shows that the mooney scorch time of rubber-compound does not affect the increase of screw rotation speed.

3.3. Die Swell.
The die swell value after extruding process with screw rotation speed variation is shown in figure 3.

![Die Swell after extrusion](image)

**Figure 3.** The effect screw rotating speed on die swell of rubber-compound

Figure 3 above shows that the value of die swell was consecutively around 0.493, 0.536 dan 0.553 Lb-in. It shows that increasing screw rotation speed increase the value of die swell in linear approach.

4. Conclusion
Extrusion process affected the rubber-compound characteristics. It can be seen through the changes of viscosity and die swell value due to the changes of the screw rotation speed where the increase of screw rotation speed does not only change the viscosity value, but also increase the die swell value of rubber-compound. The above changes can be used to define the appropriate extrusion’s process parameter in order to meet the required specification of the rubber-compound output. For the following experiments, it is suggested to add the variation rotation speed of screw.

References
[1] Taşdemir M, 2004. *Journal of applied polymer science*, 93(6), 2521-2527
[2] Kim S D, Choi Y, Choi W, Choi C, and Chun Y S, 2012. Effect of Ethylene - Propylene Copolymer Composition on Morphology and Surface Properties of Impact propyleneCopolymer Macromolecular Symposia 312 No 1 pp 27-33
[3] Mehta, Sameer, Mirabella, Francis M, Rufener, Karl, and Bafna 2004. Thermoplastic olefin/clay nanocomposites: morphology and mechanical properties. *Journal of Applied Polymer Science*, 92(2), pp 928-936
[4] Zhao, Chengzhe, Wu, Guangfeng, Zhou, Chao, Yang, Haidong, Zhang and Huixuan 2006. Independence of the brittle–ductile transition from the rubber particle size for impact - modified poly (vinyl chloride). *Journal of Polymer Science Part B: Polymer Physics*, 44(4), pp 696-702
[5] Zhang, Ling, Chunzhong L, and Rui H, 2004. Toughness mechanism in polypropylene composites: polypropylene toughened with elastomer and calcium carbonate. *Journal of Polymer Science Part B: Polymer Physics* 42.9 pp 1656-1662
[6] Yu, Long, Dean, Katherine, Li, and Lin 2006. Polymer blends and composites from renewable resources. *Progress in polymer science*, 31(6), pp 576-602
[7] Yu, Zhong-Zhen, Yang, Ming-Shu, Dai, Shao-Cong, Mai and Yiu-Wing 2004 Toughening of recycled poly (ethylene terephthalate) with a maleic anhydride grafted SEBS triblock copolymer. Journal of applied polymer science, 93(3), pp 1462-1472

[8] Jiang, Long, Wolcott, Michael P, Zhang and Jinwen, 2006 Study of biodegradable polylactide/poly (butylene adipate-co-terephthalate) blends. Biomacromolecules, 7(1), pp 199-207

[9] Tadmor, Zehev, Gogos and Costas G, 2013 Principles of polymer processing, John Wiley & Sons44.

[10] Stevens M J and Covas J 2012 Extruder principles and operation (Springer Science & Business Media)

[11] Rauwendaal C 2014 Polymer extrusion (Carl Hanser Verlag GmbH Co KG)

[12] Vera-Sorroche J, Kelly A, Brown E, Coates P, Karnachi N, Harkin-Jone E, and Deng J 2013 Thermal optimisation of polymer extrusion using in-process monitoring techniques Applied Thermal Engineering 53.2 pp 405-413.

[13] Vera-Sorroche J, Kelly A L, Brown E C, Gough T, Abeykoon C, Coates P D, and Price M 2014 The effect of melt viscosity on thermal efficiency for single screw extrusion of HDPE Chemical Engineering Research and Design 92.11 pp 2404-2412

[14] Yazdani, Hamid, Karrabi, Mohammad, Ghasmi, Ismaeil, Azizi, Hamed, Bakhshandeh and Gholam R, 2011 Devulcanization of waste tires using a twin - screw extruder : The effects of processing conditions, Journal of Vinyl and Additive Technology, 17(1), pp 64-69

[15] Liang J Z 2008 Effects of extrusion conditions on die-swell behavior of polypropylene/diatomite composite melts Polymer testing 27.8 pp 936-940.

[16] Rides M and Allen C R G 1996 Intercomparison of extrudate swell measurements using capillary extrusion rheometers for a polyethylene melt NPL Report CMMT A9