EFFECT OF VARYING CONDITIONS IN THE MIXING AND STIRRING ON PROPERTIES OF ASPHALT CEMENT GRADE 80/100 MODIFIED WITH CRUMB RUBBER AND STYRENE BUTADIENE STYRENE POLYMER

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Abstract

The quality of crumb rubber modified asphalt cement is generally not up to the required standard. Therefore, continuous studies have been performed to find out how to improve the properties of the crumb rubber modified asphalt cement. Various additives are used with different formulas and production processes, yet the results of the tests are not fully understood. In this experiment, the focus was on the varying conditions of the mixing and stirring process while using crumb rubber and styrene butadiene styrene polymer as additives for the modified asphalt. Asphalt cement of grade 80/100 was modified using 5 wt% crumb rubber and 4 wt% styrene butadiene styrene polymer with an inexpensive mixing and stirring process that can control the speed of the stir to be constant. The other conditions in the process that varied included the temperature and the stir time. The temperatures used for the mixing and stirring process were 140°C, 160°C, and 180°C and the duration times were 30, 60, and 90 min for each set of samples. After the mixing and stirring process, each sample was analyzed to find out the physical and mechanical properties. The properties tested included the penetration, softening point, ductility, flash point, and weight loss due to heat. The results obtained, which were analyzed based on the TISI 2156-2547 standard, indicated that modified asphalt cement of grade 80/100 under processing conditions that use 5 wt% crumb rubber, 4 wt% styrene butadiene styrene polymer, a controlled temperature of 180°C and a mixing and stirring duration of 30 m resulted in a product that passed the criteria of the TISI 2156-2547 standard. The resulting properties of the modified asphalt cement of grade 80/100 had a penetration value of 57.85 (0.01 mm), flash point of 315°C, softening point of 73°C, ductility at 90.5 cm., and weight loss through the thin film oven test of 0.16%.

Keywords: **Asphalt, crumb rubber, polymer modified, SBS polymer**

Introduction

The majority of highways constructed in Thailand use asphalt concrete for the surfaces. The quality of these surfaces is controlled under the asphalt concrete construction standard, Standard No. DOH-S-408/2532 (Department of Highways, 1989). However, it has been found very often

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that the asphalt concrete surfaces fail prior to their expected lifetime (Witayakul and Kunthawethep, 1996). This observation also covers polymer-modified asphalt cement which prolongs the utilization time of asphalt road surfaces but with a much higher investment cost. Therefore, further research to improve the quality of the modifiers for asphalt cement with various polymers at cheaper prices to substitute for the expensive synthetic polymers is required.

There is research that shows positive results for crumb rubber modified asphalt cement in terms of reduced cracking on surfaces, increased resistance to change in temperature, and increased adhesiveness between the asphalt and other aggregates (Bethune, 1978). Both wet and dry mixed crumb rubber modified asphalt cements (AC) have better engineering qualities than normal AC (Poonsawat, 2001). Enhancing the quality of AC using crumb rubber has found that there are some problems that degrade the quality of the asphalt such as causing it to have a higher hardness value (lower penetration value), less elasticity (Witayakul and Kunthawethep, 1996), higher viscosity, and possibly creating a separation between the crumb rubber and asphalt as high as 25% of the mixture (Poonsawat, 2001); this is more than for any polymer modified asphalt in general for which the separation is approximately only 2–4%. Crumb rubber modified asphalt is a nonhomogeneous mixture which is a bad quality for asphalt and may be the cause of a lower lifetime for the road surface. Therefore, most crumb rubber modified asphalt is unqualified under the TISI 2156-2547 standard (Thai Industrial Standards Institute, 2004).

In recent years research has been performed focusing on fixing the problems of crumb rubber modified asphalt. The targeted variable was the production process or using polymer additives as a secondary additive in the modified AC mixture. Extensive studies on the use of recycled tire crumb rubber in asphalt underlined the importance of the role of the processing conditions on the improvement of the mechanical engineering properties of this asphalt (Billiter *et al*., 1997). Time, temperature, and shear properties are crucial chemical compatibility and processing conditions required for obtaining the desired mechanical properties and stable formulation during hot-storage for asphalt and synthetic binders (Navarro *et al*., 2005). The composition and mechanical behavior of materials may be changed due to the process which can lead to undesirable in-service properties (Navarro *et al*., 2001). Asphalt modification processes are generally performed at high temperatures for several hours. Exposure to high temperatures over a long period of time may lead to aging phenomena and, as a result, hardening of the asphalt which in turn contributes to the lowering of the desired mechanical properties (Mastrofini and Scarsella, 2000; Scarsella *et al*., 1999). The experiment for enhancing the qualifications of 80/100 AC with SBS polymer and crumb rubber found that the mixture of the additives clearly improves the elasticity of the binder and shows higher viscosity values and a lower tangent delta compared to binders without SBS additives (González *et al*., 2012). In another experiment to enhance the properties of 60/70 AC which used crumb rubber along with SBS polymer at different conditions, it was found that the best percentage of the additives in the mixture are 5 wt% crumb rubber and 4 wt% SBS polymer (Phetcharat, 2013). This combination was found to best enhance the quality of 60/70 AC to qualify under the TISI 2156-2547 standard. However, there are still some limitations in the qualifications of the properties including the penetration value, softening point, and elasticity which are lower than the standard. More recent experiments on 80/100 AC with crumb rubber and SBS polymer additives (Phetcharat, 2014) found that the best proportions of additives which qualify the mixture to the TISI 2156-2547 standard were 5 wt% crumb rubber and 4 wt% SBS polymer. Still, the softening point for this mixture is lower than 70°C which is lower than the acceptable standard. One thing to note from both experiments was that the best properties were achieved when the proportions of the additives were 5 wt% crumb rubber and 4 wt% SBS polymer. The only difference was that, at this ratio, the properties of 80/100 AC were enhanced more than those of 60/70 AC.

Even though many research papers in the past have been devoted to the study of processing the variables of asphalt materials such as temperature, time, surrounding atmosphere, and type of device, the influence of the process on both the mechanical properties and storage stability of the resulting binders is not yet well understood. The lack of understanding is particularly on the subject of when the asphalt is modified using components that are insoluble such as polyolefins and crumb rubbers. Consequently,with the aim of optimizing the formulation of asphalt modified with low solubility materials, this work focuses on the processing conditions that are most appropriate for 80/100 AC modified with 5 wt% crumb rubber and 4 wt% SBS polymer. The variations were set for the physical process of the mixing and stirring time and the mixing temperature. It was expected that the result of the experiment would show the variables in the mixing and stirring process which best enhance the properties of 80/100 AC. It was found that if crumb rubber was used in the asphalt modification process it enhanced the mechanical properties to about the same level as using synthetic polymers. If crumb rubber is used in this process, it also means that waste which is difficult to manage is being recycled for better use, which is a much sounder option for the environment. Other than that, this material option can also contribute to the reduction of the initial investment cost of polymer-modified asphalt.

Materials and Methods

The materials used in the experiments were asphalt cement of grade 80/100 (80/100 AC), styrene butadiene styrene polymer (SBS polymer), and crumb rubber. The properties of the 80/100 AC were tested in accordance with the TISI 851-2547 standard (Thai Industrial Standards Institute, 1999), as shown in Table 1. Then, an SBS polymer (Calprene® C 501), in porous crumb form was applied. It had a 31% styrene content and polymeric properties, as shown in Table 2. The crumb rubber screened with a seive No.40 was also tested so that the material was a mixture that contained material less than 0.425 mm in size. Polymer and crumb rubber modified asphalt (PCRMA) was created using the mixing and stirring process with a constant speed.

The PCRMA was produced using inexpensive mixing and stirring equipment, as shown in Figure 1. The process began with heating the asphalt and controlling the temperature of the process. Once the asphalt had melted, 5 wt% crumb rubber and 4 wt% SBS polymer were added and the mixing and stirring process began. Heat was consistently added to the mixture during the process. There were a total of 9 scenarios for the mixture. Varying conditions were the processing temperature and the mixing and stirring time. The heat used to prepare the samples was set at 140°C, 160°C, and 180°C and the mixing and stirring times used were 30, 60, and 90 min, respectively, for each temperature.

Table 1. Properties of asphalt cement (AC)

Properties	AC 80/100	Standard TISI 851-2542
Penetration (0.1 mm)	85	80-100
Flash point (°C)	261	≤ 232
Softening point (°C)	46	45-52
Ductility (cm)	> 100	100
Loss on Heating (wt %)	0.04	≤ 1.0

Each sample was tested for its mechanical properties; the penetration test was performed and the properties analyzed against ASTM D5/D5M-13 (ASTM, 2013), the softening ring-and-ball test was performed according to ASTM D36/D36M-14e1 (ASTM, 2014), the ductility test performed according to ASTM D113-07 (ASTM, 2007), the flash point test performed according to ASTM D92-12b (ASTM, 2013), and the thin film oven test performed according to the ASTM D-2872-12e1 (ASTM, 2012). The results of the tests were analyzed against the TISI 2156-2547 standard for modified asphalt cement for use in pavement construction.

Results

Tests were made for the properties of the 80/100 AC modified with 5 wt% crumb rubber and 4 wt% SBS polymer processed at varying temperatures and mixing and stirring times. These tests included a penetration test, flash point test, softening test, ductility test, and thin film oven test.Analysis of the test results using the PCRMA) produced through the varied processes were compared to the TISI 2156-2547 standard for modified asphalt cement for use in pavement construction. The results of the penetration test, as shown in Figure 2, show the processing variables that affect the hardness properties of the PCRMA. When the temperature for the production of the PCRMA was set at 140°C, the penetration value of the sample was within the standard limit. The penetration values for the mixing and stirring times of 30 and 60 min were 55.4 and 64.7, respectively. For the PCRMA production at the processing temperature of 180°C and mixing and stirring time of 30 min, the penetration value was within the standard limit at 57.9. However, for the PCRMA production at the processing temperature of 160°C and mixing and stirring time of 30, 60, and 90 min, the penetration values for all samples failed to reach the standard values. The modified asphalt with 5 wt% crumb rubber and 4 wt% SBS polymer in every scenario of this research had less penetration value than normal 80/100 asphalt which has a penetration value of 85.

Figure 1. Inexpensive mixing and stirring equipment

Table 2. Properties of Calprene® C-501 SBS polymer

Polymer properties	Value
1. Toluene solution viscosity 25%, Pa-s	5
2. Toluene solution viscosity 5,23%, cSt	13
3. Volatile matter, %	0.4
4. Hunterlab color	2
5. Total styrene (on polymer), %	31
6. Hardness, ° Shore A	76
7. Insolubles in toluene, 325 mesh, %	< 0.1
8. Ashe, %	< 0.35

Modification of the asphalt with the same proportion of additives but at different temperatures and mixing and stirring times results in different hardness values for the PCRMA. Therefore, the penetration value of each sample was different. The different temperatures and mixing and stirring times allow the crumb rubber and SBS polymer to dissolve in the asphalt at different levels and, therefore, cause the chemical composition to change and increase the hardness of the PCRMA from the solid solution hardening mechanism. The production process used the heat or mixing and stirring time to low cause of left some undissolved additives in the mixture. The crumb rubber produces particles which act as the reinforcement to the asphalt which make the PCRMA have better hardness properties. The amount, size, and dispersion of the crumb rubber all influence the hardness properties of the modified AC. For the processing temperature at 140°C and 160°C the mechanisms that affect the hardness of the PCRMA include both the solid solution and reinforcement mechanism but it cannot yet be identified which of them has the greater influence. High temperatures help to dissolve the crumb rubber in the asphalt. In the scenario where the processing temperature was 180°C and the mixing and stirring time was 30 min, no trace of crumb rubber was found in the PCRMA, as shown in Figure 3. Therefore, it can be concluded that at 180°C the solid solution and reinforcement mechanism should have less impact on the hardness of the PCRMA. However,

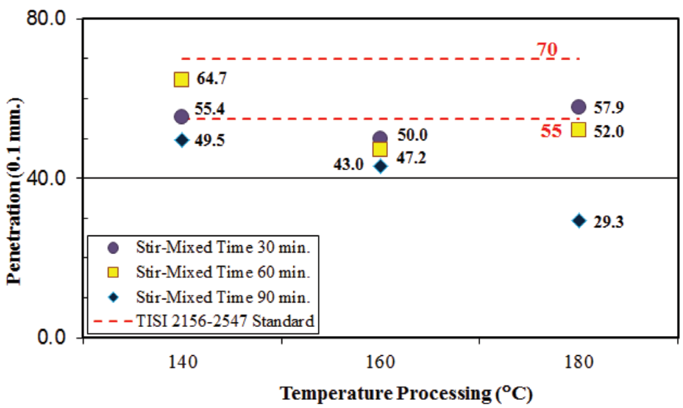
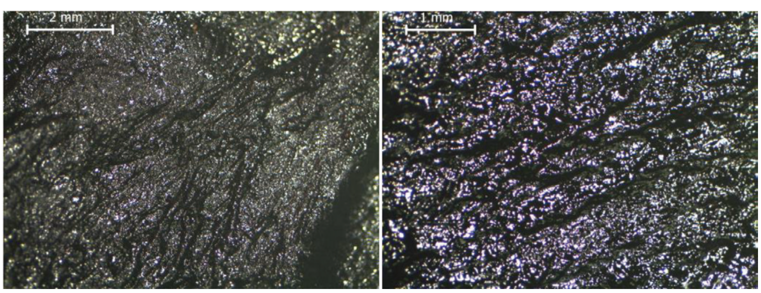


Figure 2. Penetration test results for 91% 80/100 AC with 5% crumb rubber and 4% rubber processed at varying temperatures and mixing and stirring times



(a) At low magnification (b) At high magnification

Figure 3. Photographs of 91% 80/100 AC modified with 5% crumb rubber and 4% rubber at processing temperature of 180°C and mixing and stirring time of 30 m

the 3 test results for the processing times of 30, 60, and 90 min at a temperature of 180°C showed that the resultant material was different. Previous research also supports the finding that the heat in the production process and the time that the material was exposed to the heat causes aging in the PCRMA (Lee *et al*., 2011; González *et al*., 2012). This heating process was a hardening mechanism. The scenario where a processing temperature of 180°C was used for the mixing and stirring time of 30 min yielded a sample with a penetration value of 57.9 which was within the standard limit. However, if the mixing and stirring time was increased to 60 min, then the penetration value started to decrease. This indicated that the PCRMA had increased hardness, which means that at the temperature of 180°C with a mixing and stirring time of 60 min the PCRMA went through the aging process. Likewise, if the mixing and stirring time increased to 90 min, the penetration value decreased to 29.3 which meant that the hardness of the PCRMA drastically increased and the effects of aging were dominant and impacted the hardness of the PCRMA. The production processes of PCRMA all have mechanisms which support the asphalt to have increased hardness. Therefore, if the production process was controlled appropriately, the PCRMA produced has a hardness value that is within the standard limit.

Figure 4 shows the results of the flash

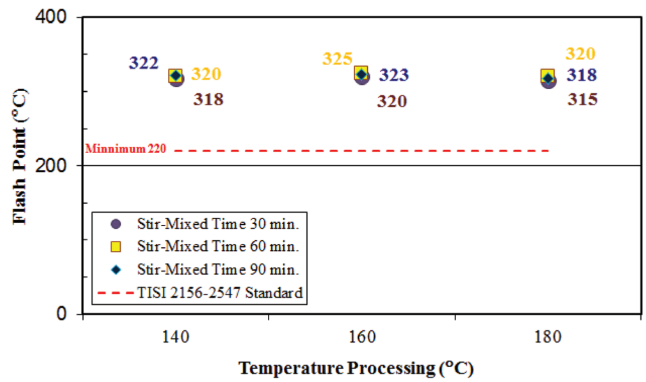


Figure 4. Flash point test results for 91% 80/100 AC with 5% crumb rubber and 4% rubber processed at varying temperatures and mixing and stirring times

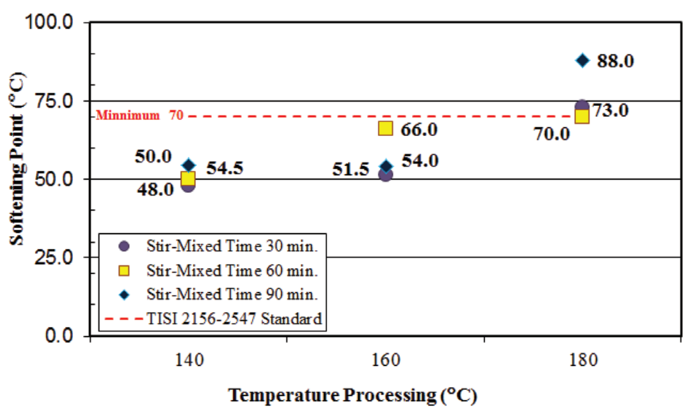


Figure 5. Softening test results for 91% 80/100 AC with 5% crumb rubber and 4% rubber processed at varying temperatures and mixing and stirring times

point test. It was found that for all the scenarios of the research the flash point values obtained fall within the standard limit and that they were all higher than 220°C. The results of the softening tests are as shown in Figure 5. Every scenario shows that at 180°C the softening points all fall within the standard values of 73°C, 70°C, and 88°C for the mixing and stirring times of 30, 60, and 90 min, respectively. The results of the softening test were the evidence which shows that, if the conditions are changed to support the production process, the softening point of the asphalt increased and fell into the standard range. When the processing temperature was at 180°C, the additives melted and became better mixed with the asphalt. This caused changes in the chemical composition and influenced the thermal properties of the PCRMA. This experiment found that when the processing temperature was 180°C, then the softening point of the PCRMA increased more than when the processing temperature was at 140°C and 160°C.

The changes in the ductility of the PCRMA due to the processing conditions were shown through the results of the ductility test, as set out in Figure 6. It was found that the changes in the heat and mixing and stirring time in the PCRMA production process affected the ductile properties of the asphalt. At a processing temperature of 160°C, the ductility values for mixing and stirring for 30, 60, and 90 min were 59.5, 75, and more than 100 cm, respectively. All these values were within the standard limit for every scenario. At a processing temperature of 180°C, the ductility values for mixing and stirring for 30 and 60 min were 90.5 and 75 cm, respectively. However, for a processing temperature of 140°C the ductility values for mixing and stirring for 30 and 60 min are lower than the standard values. The results of the ductility test for the 80 /100 AC modified with 5 wt% crumb rubber and 4 wt% SBS polymer additives when the heat and the mixing and stirring times were changed in the PCRMA production process shows that, if the appropriate method were used, then the PCRMA produced had good ductile properties. The appropriate production process helped to ensure that the mixture was better mixed and to decreased the amount of crumb rubber that did not dissolve and mix with the PCRMA and become a homogenous mixture. For a low processing temperature and low mixing and stirring time some crumb rubber remained undissolved into the mixture. The small particles were not uniform in size nor were they uniformly distributed throughout the mixture. This created a stress concentration and the beginning of a crack line once it received a pulling force (Courtney, 1990). This was something that generally happens to a material before it undergoes plastic deformation or permanently changes its shape. It causes the fragility of the material and is bad for its ductility

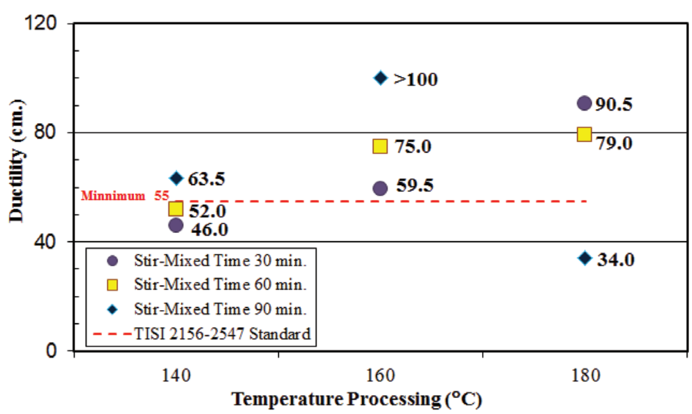


Figure 6. Ductility test results for 91% 80/100 AC with 5% crumb rubber and 4% rubber processed at varying temperatures and mixing and stirring times

properties. In the temperature processing scenario of 140°C the mixing and stirring times of 30 and 60 min have ductility values of 46 and 52 cm, respectively. These values are lower than the required standard, whereas extensive exposure to heat causes aging of the material (González *et al*., 2012). This increased the hardness of the material but, at the same time, decreased the ductility of the material, as shown from the scenario with the processing temperature of 180°C and mixing and stirring time of 90 min where the ductility value drastically decreased as compared to the mixing and stirring times of 30 and 60 min at the same temperature. The weight loss test when exposed to heat was performed using the thin film test, as shown in Figure 7. For this property, it was found that all samples yielded a rate of weight loss due to exposure to heat that complied with the standard limit of TISI 2156-2547.

Discussion

This research presented the results of varying processing conditions on the improvement of the mechanical engineering properties of 4% wt. SBS polymer and 5% wt. crumb rubber modified 80/100 AC. Different temperatures and mixing and stirring times resulted in different amounts of dissolved crumb rubber and SBS polymer in the asphalt mix. The result of this was a change in the chemical composition that directly affected that thermal properties of the PCRMA, such as its softening point and flash point. Other than that, the difference in chemical composition also affected the hardness properties of the PCRMA from the solid solution mechanism.

A low temperature or low mixing and stirring time in the PCRMA production process left some undissolved additives in the asphalt mix. These undissolved additives became particles that worked as a reinforcement for the PCRMA and increased its hardness properties. Therefore, both the solid solution and reinforcement mechanisms occured and it was difficult to specify which had more impact on the hardness property of the material. Other than that, the unevenly dispersed particles in the material are small and varied in size and shape and caused a stress concentration. At the same time, the stress concentration became the origin of the cracking point once it received tension (Courtney, 1990). This is the normal behavior before permanent plastic deformation of the material or lowered impact of plastic deformation causing poor ductility and brittle behavior.

A high temperature or long mixing and stirring time in the PCRMA production process helped to dissolve the crumb rubber in the asphalt mix. In this case the impact of the reinforcement mechanism on the hardness of the PCRMA decreased. However, high heat during production

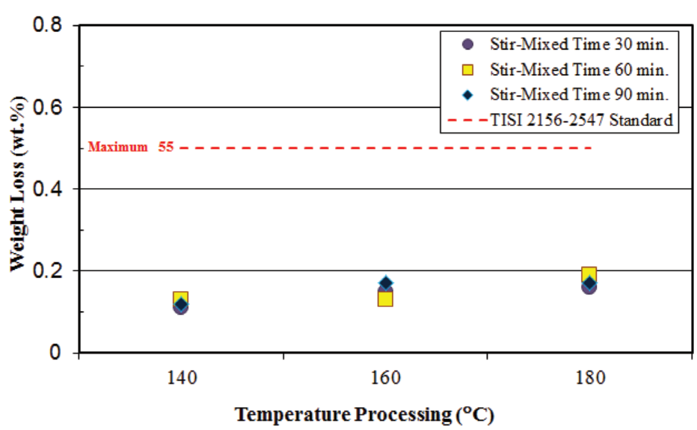


Figure 7. Thin film oven test results for 91% 80/100 AC with 5% crumb rubber and 4% rubber processed at varying temperatures and mixing and stirring times

caused the solvent to be saturated; therefore, when the PCRMA cooled down to room temperature it went through the preciptiation mechanism or age hardening process. Previous research reported that the production process of PCRMA with temperatures higher than 180°C and a mixing and stirring time of longer than 45 min led to primary aging (Lee *et al*., 2011; González *et al*., 2012). In this case, heat is the hardening mechanism that increased the hardness but decreased the ductility of the material.

Appropriate processing conditions contribute to good PCRMA properties. If too little heat and a short mixing and stirring time were used then there was an increase in the hardness but a decrease in the ductility. Meanwhile, an excessively high temperature and a long mixing and stirring time resulted in increased hardness and decreased ductility as well. The research results obtained found the conditions which are appropriate for the processing of PCRMA of 80/100 AC using 4%wt. SBS polymer and 5%wt. crumb rubber.

Conclusions

Previous experiments and research to improve the quality of asphalt cement by adding SBS polymer and crumb rubber resulted in end products that were not of the standard quality under the TISI 2156-2547 standard. The main problems were the high hardness values obtained through the penetration test and the low softening point and ductility values. Thus, this research experimented specifically to identify the appropriate conditions for the production of 4% wt SBS polymer and 5% wt crumb rubber modified 80/100 AC. The mixing apparatus used was economical in price and the mixing parameters were set at consistent speeds but used various times and temperatures during the mixing and stirring process. The temperatures for the mixing and stirring process used were 140°C, 160°C, and 180°C and the duration times were 30, 60, and 90 min for each set of samples. The results showed that the modified 80/100 AC under the mixing and stirring conditions used to produce the PCRMC with the additives being 5 wt% crumb rubber and 4 wt% SBS polymer at the control temperature of 180°C and a mixing and stirring time of 30 min resulted in PCRMC with a penetration value, flash point, ductility value, softening point, and weight loss percentage that complies with the standard criteria, as specified under the TISI 2156-2547 standard. It should be noted that the production process is very important for the quality of the PCRMC with this composition. However, if a different variation of the PCRMC is required, then the best production condition for that specific formula must be further researched.

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