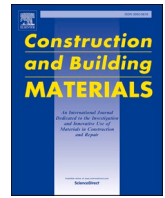




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# Influence of pandemic waste face mask on rheological, physical and chemical properties of bitumen

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## ABSTRACT

Recently, COVID-19 has appeared as an international pandemic, leading to serious risks for humans. Using face masks is one of the most common measures in a wide-ranging prevention program that could control the COVID-19 dissemination. Face masks are typically composed of non-biodegradable and non-renewable polymers based on petroleum, which are harmful to nature and lead to health problems. In the present study, disposable face masks, the use of which has increased due to the Covid-19 pandemic throughout the world and which cause environmental pollution, were divided into very small pieces and utilized as a modifier in the bitumen binder. Therefore, this study aimed to provide a solution to such a significant environmental problem. Five different ratios of waste mask and the single ratio of styrene-butadienestyrene (SBS) were added to the pure binder and the rheological, physical, and chemical properties of the modified binders were compared. The result showed that adding a waste mask and SBS to the pure bitumen caused increases in binders' softening point and viscosity and reductions in the penetration value. Waste mask modifications were able to better maintain its elastic properties both at low stress and high-stress levels with increasing temperature. 3% SBS was the binder most affected by temperature rise. As a result, it has been determined that binders containing more than 2% waste mask have better performance characteristics than binders containing 3% SBS in terms of physical and rheological properties.

## 1. Introduction

The novel Coronavirus was officially entitled SARS-CoV-2, and the infection it caused was called COVID-19 [1]. Because of its rapid spread as a result of human-to-human transmission, the World Health Organization (WHO) acknowledged the disease as a pandemic and a "Public Health Emergency of International Concern" on 11 March 2020. Personal protective equipment (PPE) became compulsory to avoid contamination of health professionals providing medical care to asymptomatic and symptomatic patients to keep national healthcare systems operating [2]. WHO stated that seventy-six million gloves, eighty-nine million medical masks, and 1.6 million goggles were produced per month to meet the PPE needs of healthcare professionals [3]. Nevertheless, public concerns about this extremely infectious virus have also paved the way for the utilization of PPE by the community to contain the disease the contagion rate of which remains unquantifiable on a global scale [4]. From the early days of the outbreak of the disease,

people have been advised to cover their faces or wear face masks in public, and this has been even mandated by countries [5]. Since PPEs are disposable materials, they lead to environmental pollution and pose a threat to the living environment if planned and adequate waste management is not carried out. Even if used disposable face masks are thrown into waste collection containers, the fact that they are light in weight makes them vulnerable to conditions such as wind and rain [7] and as a result waste masks can spread everywhere, resulting in pollution in the living environment (Fig. 1). In particular, these wastes reach the seas and oceans and become a threat to the ecosystem.

At present, the main recycling methods of waste masks include high-temperature incineration, landfill collection, mechanical recycling, and chemical recycling [8]. High-temperature combustion requires high thermal energy. In addition, it produces various toxic by-products that will cause serious environmental pollution. The landfill collection method uses microorganisms in the soil to decompose the polymers. This process takes a long time and also causes secondary pollution in the soil.

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Fig. 1. Mask waste in the living environment.

Mechanical recycling method, waste masks are pulverized to produce low-grade products for further use. It is the use of melt processing to combine waste masks with polymer or inorganic fillers. The chemical recycling method is to convert high molecular polymers into small molecular compounds through chemical processes such as pyrolysis or gasification and then reconstitute them to form new materials. This process is complex and consumes a lot of energy. For this reason, the use of existing recycling and treatment methods of waste face masks does not provide benefits in terms of environmental pollution and the economy. Plastic wastes can be partially used as aggregate in construction materials. Plastic waste has been used in various construction materials such as brick production [6,9–11], coatings [12,13], aggregate in concrete [14–17], soil material [18,19], and asphalt binder/mixture [20–27].

It is very important to improve bituminous mixtures' properties since the poor performance will require more maintenance and repair, and in some cases it will even lead to the replacement of pavement, resulting in the consumption of more materials and natural resources. The use of waste materials both as an additive to the binder and as aggregate/filler in hot bituminous mixtures is a significant environmental development.

Mashaan et al. added waste Polyethylene Terephthalate (PET) as an additive to the bitumen binder and examined its performance properties. The results indicated that the supplementation of PET increased the rutting resistance, aging resistance, elastic properties, and fatigue life of bituminous binders [28]. Haider et al. investigated the moisture damage properties of hot bituminous mixtures obtained by using bitumen modified with waste plastic materials. They demonstrated that the addition of high-density polyethylene increased the adhesion properties and moisture damage resistance [29]. El-Naga and Ragab used Polyethylene terephthalate (PTP) waste plastic material in bitumen modification. They applied conventional binder tests to the modified binders they obtained, and Marshall Indirect Tensile and tire traction tests to the mixture samples. The results revealed that the addition of PTP lowered the penetration values of bituminous binders and increased the point of softening. They also stated that the strength of the mixtures had a tendency to increase and the supplementation of 12% PTP enhanced the service life of the asphalt pavement by 2.81 times [30]. Li et al. investigated the use of waste plastics in hot bituminous mixtures as an anti-peeling agent. The results demonstrated that the waste plastic increased the moisture resistance of the mixture and thus can be used as an anti-peeling agent [31]. Ahmadinia argues that cheaper and recycled materials should be used in the production of polymer-modified hot bitumen mixtures. Therefore, he investigated the effect of adding waste plastic on the stone mastic asphalt's engineering properties. The mechanical and volumetric properties of the stone mastic asphalt samples having certain percentages of waste plastic were investigated and the appropriate additive ratio was found as 6% [32]. Kakar et al. investigated the mechanical and thermal behaviors by adding two different types of waste polyethylene as a modifier to the bitumen binder. The results indicated significant improvements in high-temperature performance parameters such as rutting compared to commercial polymer-modified binders [33]. Wu and Montalvo carried out a review study on the usability of waste plastics in asphalt pavement materials. The authors presented in detail the various types of waste plastics and recycling methods. Overall, they concluded that the addition of plastic waste to hot bituminous mixtures results in ameliorations in engineering

parameters such as fatigue resistance, rutting, stiffness, and moisture damage [34].

In the present study, disposable face masks, the use of which have increased due to the Covid-19 pandemic and caused environmental pollution in the world, were divided into very small pieces and used as a modifier in the bitumen binder. The use of waste masks as modifiers in bituminous binders was studied for the first time. Modified bitumen was obtained by adding masks at 1%, 1.5%, 2%, 2.5%, and 3% by weight of bitumen binder, then softening point, penetration, and Rotational Viscometer (RV) tests were conducted on modified bitumen. In addition, the high-temperatures performance classification was determined by employing the Dynamic Shear Rheometer (DSR) device, also the rheological behavior was evaluated at different rates of loading and temperatures. Then, Bending Beam Rheometer (BBR) test was implemented on modified and pure binders to detect low-temperature performance. The results of the test of binders prepared with waste mask and the results of a binder prepared with SBS polymer were compared.

## 2. Materials and methods

### 2.1. Bitumen

As a pure binder, B 50/70 bitumen with a density of 1.015 g/cm<sup>3</sup> was utilized. The bitumen used in the study was obtained from TUPRAŞ Batman Refinery. Its general features were presented in Table 1.

### 2.2. Waste mask material

Disposable face masks are manufactured using polymers including polyurethane, polyacrylonitrile, polycarbonate, polystyrene, polypropylene, polyester, and polyethylene [35]. These masks consist of 3 layers: the outer layer (made up of nonwoven fibers that are mostly colorful and water-resistant), the middle layer (i.e. melt-blown filter), and the inner layer (i.e. soft fibers). The outer layer is composed of spun-bond or thermo-nonwoven polypropylene fabric (Fig. 2) [36]. The outer layer, which should be water-repellent or impermeable, is usually harder and more colorable. The middle layer is made of melt-blown or spun-bond non-woven propylene, PES (polysulfone), or their mixtures. The middle layer has a high fiber density and is a fluffy layer to ensure better filtration. The inner layer is composed of spun-bond or thermo nonwoven propylene, PES, or their mixtures. The inner layer directly contacts the skin of the individual. There may be differences in the composition of the product among manufacturers. Therefore, various face mask types and descriptions of them are presented in Table 2 [37].

The interaction between the modified bitumen additives may occur in various ways. In one way, the modified bitumen exists in a separate phase. The material exhibits modifier properties. In another way, the modified bitumen additive creates an interface with the bitumen and provides further elasticity based on the mechanical properties of the material. Another way the modified bitumen additive interacts with the bitumen occurs while creating a bond with the material to provide elasticity and rigidity. The use of the waste surgical mask covers all of these processes. Additionally, the surgical masks can be obtained, ground, stored, and used conveniently.

Table 1  
General features of bitumen.

Properties	Unit	Standard	Results
Penetration	mm <sup>-1</sup>	EN 1426	56
Softening point	°C	EN 1427	53.3
Flash Point	°C	EN ISO 2719	245
Density	g/cm <sup>3</sup>	ASTM D70 – 18a	1.015
Elastic Recovery	%	EN 13,398	30
Viscosity 135 /165	°C	ASTM D4402	737.5/225
Mixing temperature range	°C	–	159–165
Compaction temperature range	°C	–	145–151

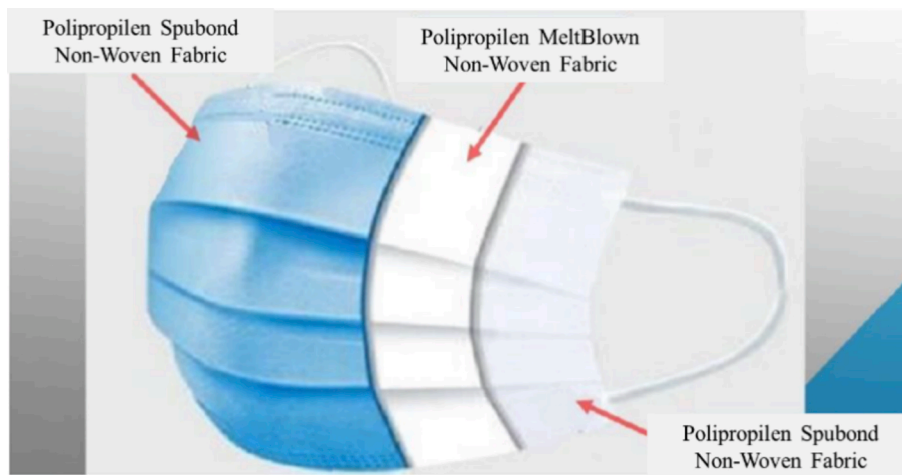


Fig. 2. Surgical mask layers [36].

Table 2

The brands of different manufacturers and their descriptions [37].

Mask Type	Description
Tie-on surgical face mask	3-ply, pleated rayon outer web with polypropylene inner web
Classical surgical mask, Blue	3-ply, pleated cellulose polypropylene, polyester
Sofloop extra protection mask	3-ply, pleated blended cellulosic fibers with polypropylene and polyester, ethylene methyl acrylate strip
Aseptex fluid resistant	Molded rayon and polypropylene blend with an acrylic binder
Surgine II cone mask	Molded polypropylene and polyester with cellulose fibers
Surgical grade cone style mask	Molded polypropylene

Masks used to obtain modified bitumen were collected in waste collection containers. As a result of preliminary studies on the persistence of the COVID-19 virus in homes, hospital environments, and on surfaces, it was revealed that the virus can live on surfaces or plastic items for up to 72 h following direct exposure [38]. For this reason, after the collected waste masks were kept in an isolated environment for 96 h, they were completely ground except for the metal strips in the masks. The dimensions of the ground masks were 2–4 mm on average (Fig. 3).

While the waste masks were used in the study, they were used in a mixed manner regardless of the department, mask brand, or mask type.



Fig. 3. The ground waste mask was used in the study.

It was taken directly from the mask collection area of the hospital. The reason for such use is because waste masks are stored in a pile and they are dangerous, it is very difficult to separate them. In addition, using it by separating is not an ergonomic method. Therefore, in this study, the effects on bitumen were evaluated by using mixed waste masks. In this way, the use of waste masks is practical and economical. In Fig. 4, the SEM images of waste surgical masks and SBS-modified bitumen were presented. As the waste mask ratio in the binder increases, the additive covers a larger area of the bitumen. While the additive appears as tiny points or clusters at lower additive contents, high additive contents result in larger clusters that cover the surface area. Furthermore, it can be stated that the embedding of various additive pieces into the bitumen and the simultaneous and fine interaction of the additive on the surface indicate that the additive is soundly bound in the bitumen. As the waste surgical mask ratio increases, the interaction between the bitumen and the waste surgical mask becomes stronger. For the SBS additive, the dispersion of the additive can be observed on the surface of the bitumen.

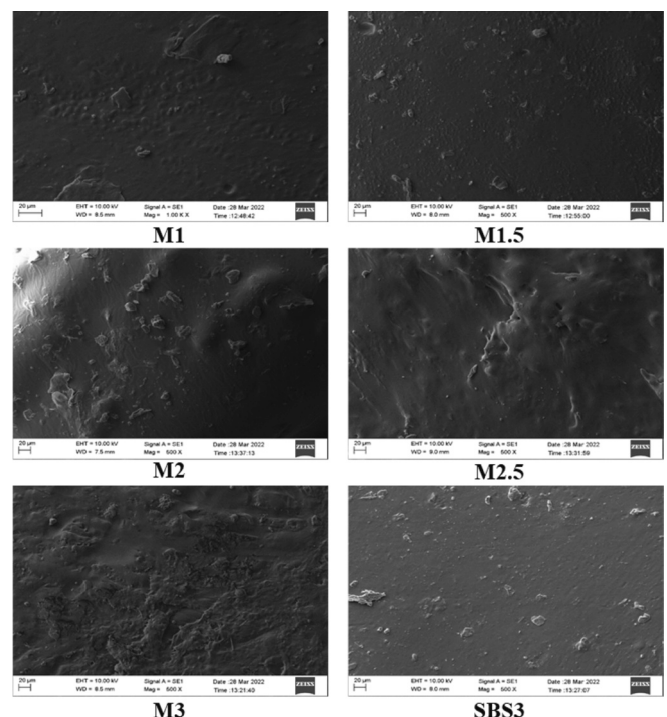


Fig. 4. SEM images of waste masks and SBS.



### 2.3. Modified bitumen preparation

Modified bitumen was obtained by adding 1%, 1.5%, 2%, 2.5%, and 3% ground waste masks and 3% SBS by weight of pure bitumen. The mask-modified binders were coded as M1, M1.5, M2, M2.5, and M3, and the SBS-modified binder as SBS3. The pure binder was expressed as C. The preparation process of waste mask and SBS modified bitumen was carried out in the following order.

- First, pure bitumen was warmed up in the oven at  $180 \pm 5 \text{ }^\circ\text{C}$  for 30 min to melt.
- The fluidized bitumen was poured into the metal mixing chamber as 500 g.
- To create a homogeneous heat source, after the bitumen poured into the metal chamber was placed in the thermal jacket on the heater source conditioned at  $180 \pm 5 \text{ }^\circ\text{C}$ , it was kept until the heater reached the thermal balance of  $180 \pm 5 \text{ }^\circ\text{C}$ .
- Waste masks were poured into the hot bitumen in percentages determined by the weight of the bitumen.

Bitumen containing waste masks was prepared using a mechanical mixer operating at 1000 rpm for 60 min [39]. To prevent the aging effect that occurs during the preparation of modified bitumen from affecting the results, the pure binder was also subjected to the same mixing process. The detailed experimental study plan is presented in Fig. 5.

### 2.4. Conventional binder tests

The standard penetration test is described as the depth a 100 g needle penetrates vertically in bitumen for 5 s at  $25 \text{ }^\circ\text{C}$  [40]. At least 3 samples are taken from points on the surface not less than 1 cm to one side and each other, and the arithmetic mean of the acceptable measurements is considered as the penetration value of the sample. The temperature at which the bitumen becomes fluid is the softening point of the bitumen. To determine the softening point, 3.5 gr. weight steel ball is placed on the bitumen sample poured into the standard softening point ring made

of brass which is then placed in a  $5 \text{ }^\circ\text{C}$  water bath in a beaker. The beaker is heated to increase the temperature of the water by  $5 \text{ }^\circ\text{C}$  per minute. The temperature of the water when the bitumen sample in the ring softens and touches the bottom plate 25 mm below the ring is accepted as the bitumen binder's softening point value.

### 2.5. Rotational Viscometer test

To identify the viscosity features of bituminous binders at elevated temperatures, The Rotational Viscometer (RV) test is utilized. For this purpose, "Brookfield Viscometer" is used in agreement with the AASHTO T316 standard [41]. In the experiment, using a motor, the shaft is rotated regularly at 20 rpm and viscosity evaluations are made. Generally, in the RV test applied on the original binders, the value of viscosity at  $135 \text{ }^\circ\text{C}$  is required not to pass over 3 Pa.s.

### 2.6. Dynamic shear Rheometer test

#### 2.6.1. Detection of phase angle ( $\delta$ ) and Complex shear modulus ( $G^*$ )

The complex shear modulus demonstrates the total resistance against deformation during the torsion of the binder for a given period, whereas the angle of phase is the delay between the resulting shear strain and the applied shear stress. A wider phase angle indicates a more viscous bituminous binder. Permanent deformation is checked by limiting the rutting parameter ( $G^*/\sin\delta$ ) to values bigger than 1.0 kPa for unaged original binders [42]. The test was conducted on pure and modified bitumen with a stress-controlled Bohlin DSR II rheometer according to the ASTM D7175 standard. The experiment was carried out at  $52 \text{ }^\circ\text{C}$ ,  $58 \text{ }^\circ\text{C}$ ,  $64 \text{ }^\circ\text{C}$ ,  $70 \text{ }^\circ\text{C}$ ,  $82 \text{ }^\circ\text{C}$ , and  $88 \text{ }^\circ\text{C}$  at a frequency of 1.59 Hz with a diameter plate of 25 mm and plate gap of 1 mm. Rutting parameters and phase angles were figured out to identify the high-temperature performance and elastic behavior of the binders.

#### 2.6.2. Multiple Stress Creep Recovery (MSCR)

The Multiple Stress Creep Recovery (MSCR) test was carried out by the AASHTO T350 standard. Due to rutting occurring in the early stages

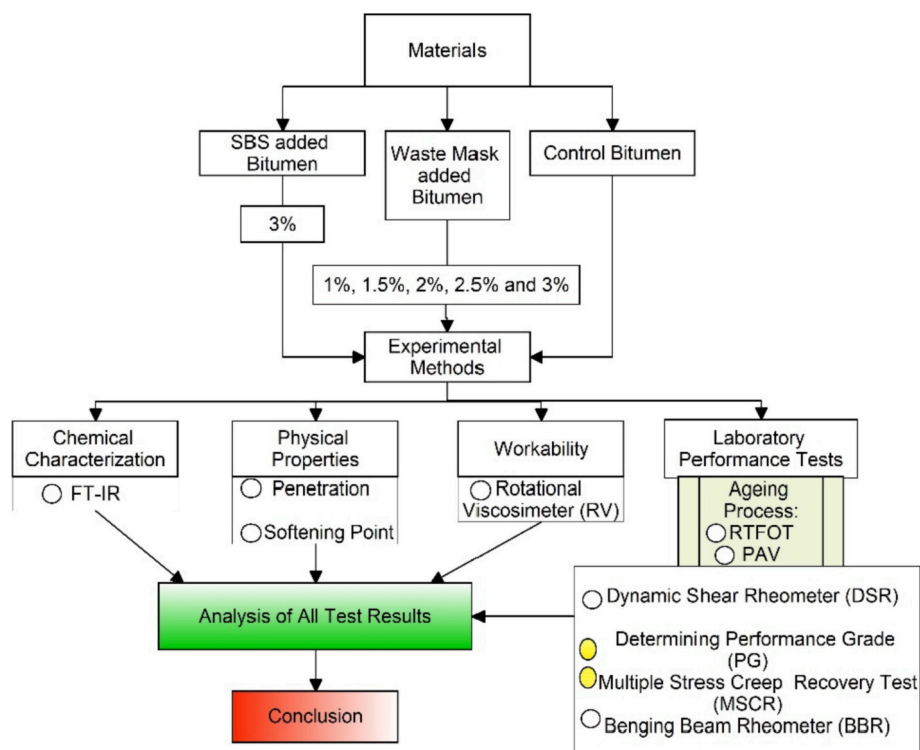


Fig. 5. The framework of the experimental study.

of the pavement, the test requires short-term aging of the binders. Therefore, the RTFO test (rolling thin film oven) is applied to samples according to AASHTO T-240 before the MSCR test. MSCR tests were done at 64 °C, 70 °C, 76 °C, and 82 °C through a 25 mm plate on short-term aged modified and pure binders. The test was applied to the binders at a stress level of twenty cycles of 0.1 kPa and ten cycles of 3.2 kPa. Each cycle consists of a recovery time of 9 s after the application of the shear stress for 1 s (Fig. 6). Shear stress of 0.1 kPa defines the attitude of a binder in the linear viscoelastic area, whereas a stress level of 3.2 kPa describes the attitude in the nonlinear viscoelastic area for pure and modified binders. This study aims to determine whether pure bitumen to which waste masks and SBS were added affected the elastic recovery and rutting properties.

With the MSCR test, two parameters are obtained in line with AASHTO M350: percent recovery (R) and permanent creep compliance ( $J_{nr}$ ). Average percent recovery (R) values for bituminous binders are calculated based on Formulas 1 and 2 at the shear stress level of 0.1 (R0.1) and 3.2(R3.2) kPa, respectively [43].

$$R_{0.1} = \frac{\sum_{N=11}^{20} [\epsilon_r(0.1, N)]}{10} \quad (1)$$

$$R_{3.2} = \frac{\sum_{N=21}^{30} [\epsilon_r(3.2, N)]}{10} \quad (2)$$

Here,  $\epsilon_r(0.1, N)$  and  $\epsilon_r(3.2, N)$  indicate the percent recovery at the stress level of 0.1 and 3.2 kPa, respectively, in the number of N cycles, and N represents the number of cycles at each level of stress. The  $J_{nr}$  parameter was determined to have a higher correlation with the rutting resistance according to the Superpave PG criterion [43]. The calculation of permanent creep compliance values for 0.1 kPa ( $J_{nr0.1}$ ) and 3.2 kPa ( $J_{nr3.2}$ ) is shown in Formulas 3 and 4.

$$J_{nr0.1} = \frac{\sum_{N=11}^{20} [J_{nr}(0.1, N)]}{10} \quad (3)$$

$$J_{nr3.2} = \frac{\sum_{N=21}^{30} [J_{nr}(3.2, N)]}{10} \quad (4)$$

MSCR test is focused on how the grade bumping is determined according to the traffic level. For  $J_{nr3.2}$  values lower than 4.5  $\text{kPa}^{-1}$ , 2.0  $\text{kPa}^{-1}$ , 1.0  $\text{kPa}^{-1}$ , and 0.5  $\text{kPa}^{-1}$ , the high-temperature performances are graded as S, H, V and E, respectively, which indicates Standard, Heavy, Very heavy, and Extremely heavy traffic loadings. To make a distinction in the non-recoverable creep compliance ( $J_{nr\text{diff}}$ ) between 0.1 kPa and 3.2 kPa stress levels.

this grading classification also needs a 75% max value [43]. The

calculation of the  $J_{nr\text{diff}}$  value is presented in Formula 5.

$$J_{nr\text{diff}} = \frac{(J_{nr3.2} - J_{nr0.1})}{J_{nr0.1}} * 100 \quad (5)$$

## 2.7. BBR test

Bending Beam Rheometer (BBR) refers to a device employed to determine the hardness of the bituminous binder at low service temperatures and to evaluate the thermal crack potential of the bitumen binder. Load and deflection are utilized to determine the creep hardness (St) and creep rate (m-value) of the binder at the finish of the test. The test was done on long-term aged binders at -12°C in line with AASHTO T313. Low creep stiffness and high creep rate (m-value) are favorable conditions for good elastic behavior at low temperatures. Hence, determining “ $\lambda$ ”, which refers to the ratio of creep stiffness to m-value values, stands out as a more accurate evaluation. Low “ $\lambda$ ” values indicate flexible behavior at low temperatures [44].

## 2.8. FTIR test

Over the past few years, with the support of the asphalt industry, state highway construction units and the Strategic Highway Research Program (SHRP) have conducted certain studies in some countries on asphalt material chemistry. Fourier Transform Infrared Spectroscopy (FTIR) is a method used to identify chemical functional groups in an environment. Chemical functional groups are atomic groups that are responsible for different reactions within the compound [45]. In the present study, Bruker Tensor 27 Fourier transform infrared spectroscopy (FTIR) was used. In the experiment, the spectrum range was selected as 4000–500  $\text{cm}^{-1}$ . In the current study, the ratio of carbonyls (C = O) and sulfoxide (S = O) to saturated C = C vibrations to analyze oxidation and rejuvenation. The C = O, S = O and C = C vibration bands were about 1699  $\text{cm}^{-1}$ , 1032  $\text{cm}^{-1}$  and 966  $\text{cm}^{-1}$ , respectively. The carbonyl and sulfoxide indexes used to determine aging were calculated with the Formulas 6, 7, and 8 [45–49].

$$I_{C=C} = A_{966} / \sum A \quad (6)$$

$$I_{S=O} = A_{1030} / \sum A \quad (7)$$

$$I_{C=O} = A_{1700} / \sum A \quad (8)$$

where  $A_{1700\text{cm}^{-1}}$  is the area of the carbonyl band with the center at 1700  $\text{cm}^{-1}$  (calculated for the range of 1650–1750  $\text{cm}^{-1}$ ),  $A_{1030\text{cm}^{-1}}$  is

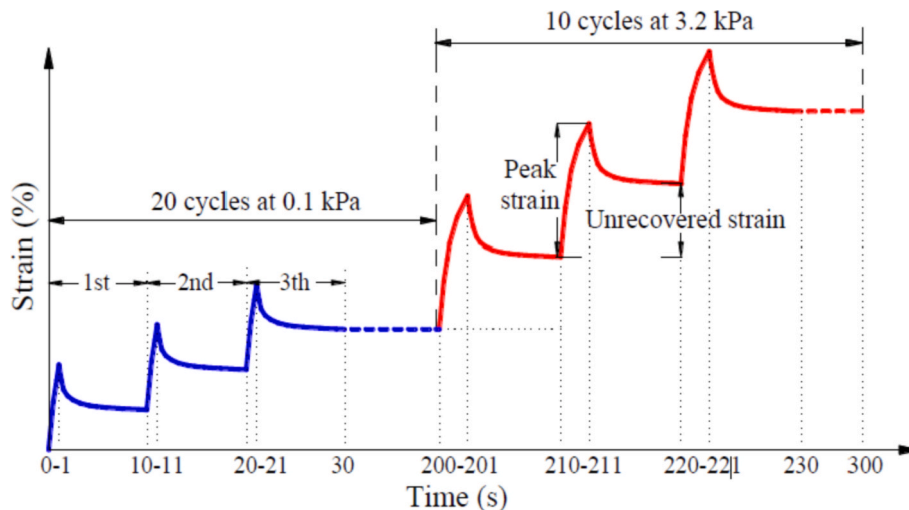


Fig. 6. Schematic representation of the MSCR system.

the area of the sulfoxide band with the center at  $1030\text{ cm}^{-1}$  (calculated for the range of  $980\text{--}1080\text{ cm}^{-1}$ ),  $A_{966\text{ cm}^{-1}}$  is the area of the butadiene band with the center at  $966\text{ cm}^{-1}$  (calculated for the range of  $916\text{--}1016\text{ cm}^{-1}$ ), and  $\sum A$  is the total area of the spectrum band for the range of  $600\text{--}3000\text{ cm}^{-1}$ .

### 3. Results and discussion

#### 3.1. Results of conventional binder tests

The change in the additive content and penetration values is presented in Fig. 7. As seen in Fig. 7, the penetration values decreased after the utilization of additives, and thus the consistency of the binders was raised. When mask waste was used in bitumen modification at the rates of 1%, 1.5%, 2%, 2.5% and 3%, the penetration value decreased by 3.51%, 31.58%, 43.86%, 49.12% and 54.39%, respectively, compared to the pure binder. A sudden decrease was observed in penetration values after 1.5% additive content. When SBS elastomer was used at a rate of 3%, the penetration value decreased by 31.58% compared to the pure binder. The penetration value of the SBS3 was the same as the penetration value of the M1.5. It is significant that as the use of waste masks was raised, the penetration values were reduced. The bituminous binders' softening point values are shown in Fig. 8.

As shown in Fig. 8, softening point values were raised after the utilization of additives. Therefore, we detected that the use of both waste masks and SBS elastomers increased the bituminous binders' high-temperature resistance. As the waste mask ratio used in bituminous binders increased, the softening point values increased regularly. The softening point values of M1, M1.5, M2, M2.5, and M3 increased by 0.37%, 1.43%, 11.23%, 11.94%, and 12.48%, respectively, compared to the pure binder (C). The softening point value of the SBS3 binder increased by 10.52% in proportion to the pure binder. The softening point value of the SBS3 binder is between the softening point values of M1.5 and M2 binders. According to the softening point values, it was determined that the use of mask waste in bituminous binders increased the thermal resistance of the binders. The binder with a high softening point demonstrates that the mixture in which it is used can maintain its viscoelastic behavior up to higher temperatures. Studies in the literature also revealed significant decreases and increases in softening point and penetration value results, respectively, with the rise of polypropylene content [50,51].

From the results obtained, it has been determined that the most effective result will be obtained in the softening point test, as in the penetration test, if 3% of the mask waste is used. Penetration and

softening values revealed that the results were compatible. As penetration values decreased, softening point values increased. A negative correlation was found between these two experiments.

#### 3.2. Results of Rotational viscosity test

The outcomes of the Rotational Viscosity test applied to bituminous binders at  $135\text{ }^{\circ}\text{C}$  and  $165\text{ }^{\circ}\text{C}$  are shown in Fig. 9. Viscosity values increased while the additive ingredient increased in waste mask modification. This result is inconsistent with other studies in the literature [52–54]. 3% additive contents showed that waste mask modification affected viscosity values greater than SBS modification. It was determined that as the highest rate used in the present study was 3% waste mask and SBS, the 3,000 cP viscosity value at  $135\text{ }^{\circ}\text{C}$  was not exceeded and therefore it did not pose a problem with workability. To have the same viscosity value as the SBS3 binder at  $135\text{ }^{\circ}\text{C}$ , the waste mask content should be used at a rate of approximately 2%. The reason for this is that the waste mask has a high intermolecular affinity compared to SBS [55]. At  $165\text{ }^{\circ}\text{C}$ , SBS 3 provided the highest viscosity value. The strength of binders containing waste masks at high temperatures was lower than binders with SBS. Compared to the C binder, viscosity values of M1, M1.5, M2, M2.5, and M3 at  $135\text{ }^{\circ}\text{C}$  increased by 1.57; 2.26; 2.85; 3.15, and 3.44 times, respectively. The SBS3 binder's viscosity value increased by 2.83 times compared to that of the C binder. At  $165\text{ }^{\circ}\text{C}$ , the viscosity values of M1, M1.5, M2, M2.5, and M3 increased by 1.36, 1.79, 2.36, 2.57, and 2.64 times, respectively, in comparison to the C binder. The viscosity value of the SBS3 binder was enhanced by 2.93 times in proportion to that of the C binder. The viscosity test results revealed that the softening point and penetration value were compatible with the test results. The softening point values increased in direct proportion to the viscosity values increased, while penetration values decreased.

#### 3.3. Rheological test results

##### 3.3.1. Complex shear modulus and phase angle

The rutting parameter ( $G^*/\sin\delta$ ) values obtained as a consequence of the DSR experiment implemented on the pure binder and binders containing waste mask and SBS are presented in Fig. 10. The rutting parameter ( $G^*/\sin\delta$ ) is utilized to detect the asphalt binder's resistance at high temperatures to permanent deformation [56]. As seen in Fig. 10,  $G^*/\sin\delta$  values rose with the enhancement in the waste mask content. The comparison of the rates of 3% showed that the M3 binder provided a greater  $G^*/\sin\delta$  value than the SBS3 binder. This result revealed that the binder modified with the waste mask was more durable to plastic

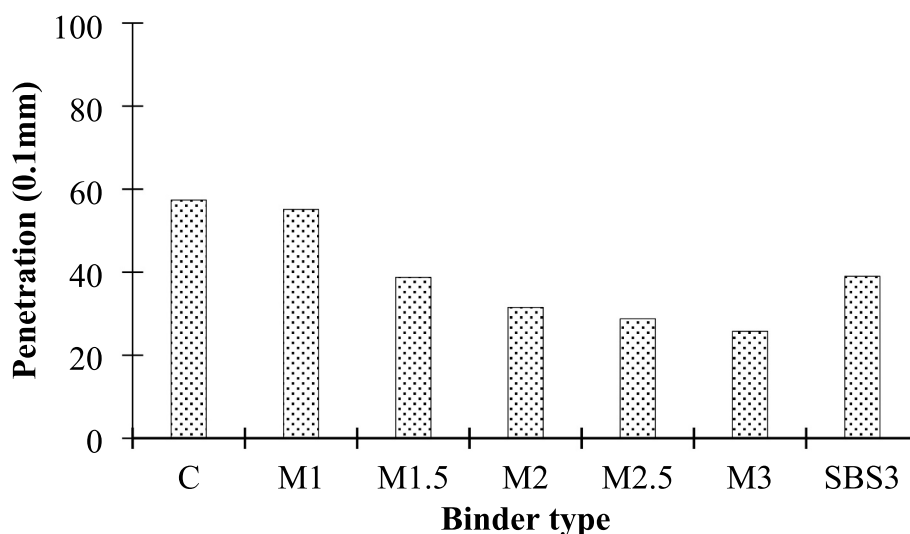


Fig. 7. Penetration values of binders.

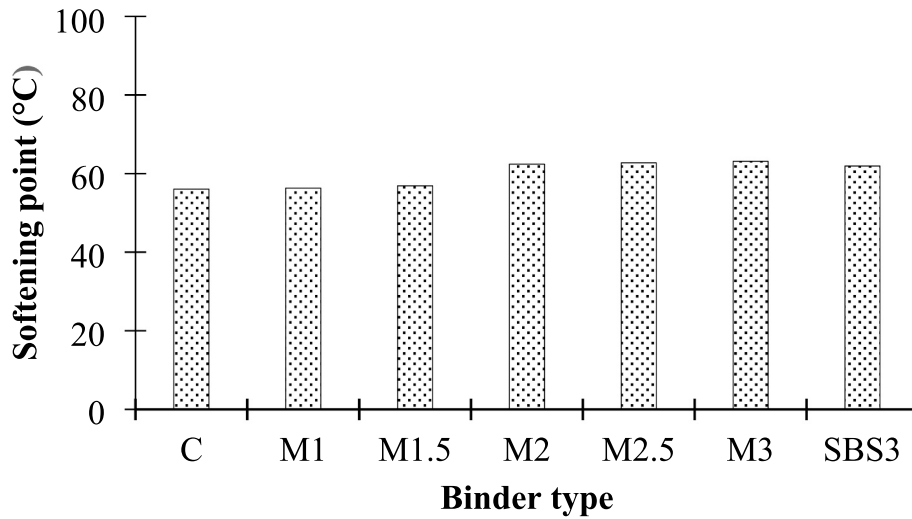


Fig. 8. The change in softening point values with additive content.

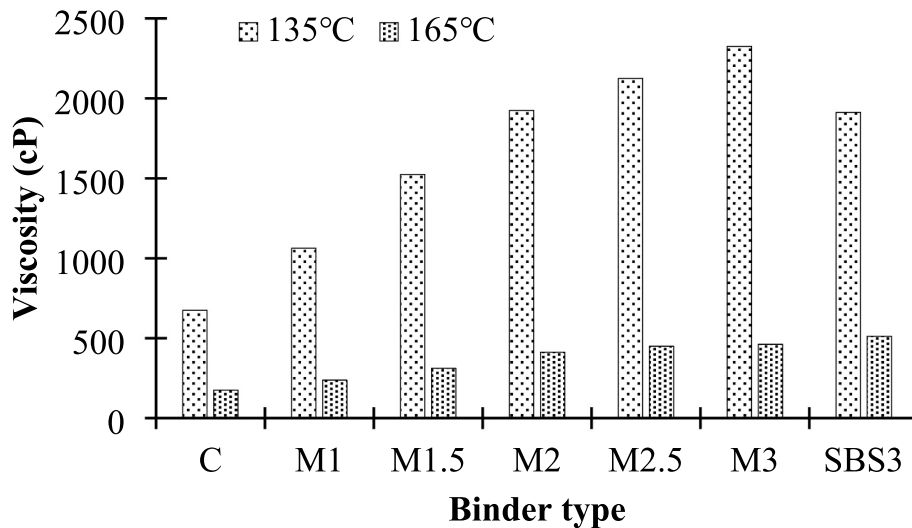


Fig. 9. The change in viscosity values at 135 °C and 165 °C with the additive content.

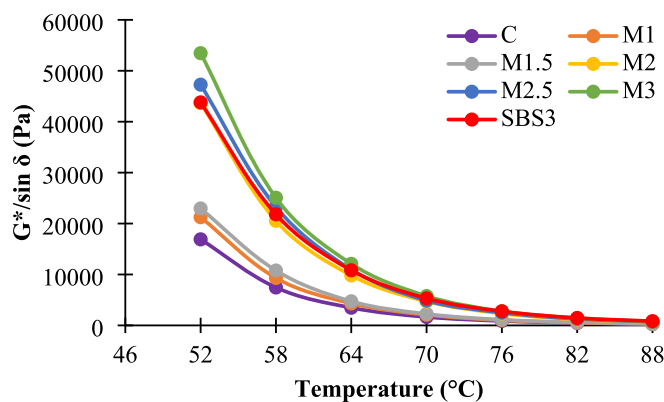


Fig. 10.  $G^*/\sin \delta$  values of bitumen.

deformation at high temperatures. At higher temperatures (88 °C), dramatic changes do not take place in the modified binders' rutting parameters compared to the pure binder.  $G^*/\sin \delta$  values of both binders containing waste mask and SBS-containing binder decreased with the

increase in temperature. These results are consistent with other studies in the literature [39,57]. Compared to the C binder,  $G^*/\sin \delta$  values of M1, M1.5, M2, M2.5, and M3 at 52 °C increased by 1.26, 1.36, 2.58, 2.80, and 3.16 times, respectively, whereas the SBS3 binder increased 2.59 times. At 88 °C, the  $G^*/\sin \delta$  values of M1, M1.5, M2, M2.5, and M3 increased by 1.12, 1.24, 2.40, 2.66, and 2.82 times, respectively, while the SBS3 binder increased 3.16 times compared to the C binder. This result supports the results of conventional binder tests. 2% waste mask content and 3% SBS content provided very similar rutting parameters. It was revealed that the waste mask additive increased the use range of the bitumen in the high-temperature region, significantly reduced the permanent deformation, and increased the elastic structure of the bitumen.

The change in the additive content of the binders and the phase angles is given in Fig. 11. The performance of the binder, which is a viscoelastic material, was greatly influenced by the coating temperature and vehicle load frequency. As the waste mask ratio in the binders increased, the phase angle values decreased. It was found that through the temperature increase the phase angle values rose for both types of modified binders. The phase angle values of the SBS3 were very similar to those of the M2. This might be a significant factor preventing asphalt pavement's permanent deformation [58]. As a general rule, the phase angle shows the ratio of the viscous component in the asphalt binder to



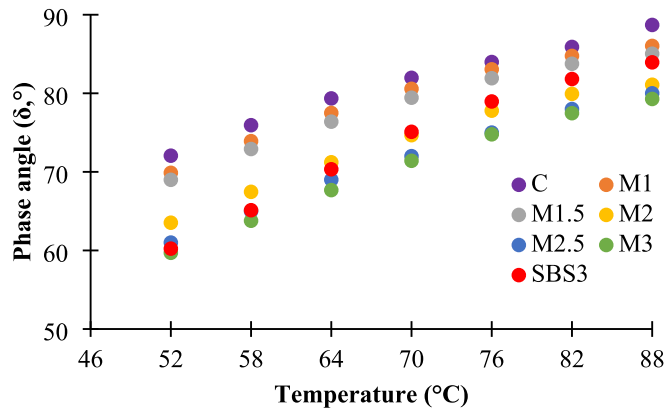


Fig. 11. The correlation between temperature and phase angle for binders.

the elastic component [59]. Wider phase angle values indicate a more viscous component and more pronounced stress hysteresis effect due to the implemented load. At the same rate, the decrease in the phase angle also increases the elastic behavior [58]. Similarly, the decline in the phase angle increases the elastic behavior [58]. The elastic behavior of the binders increased with the enhancement in waste mask content. M3 binder was found to have a more elastic property than the SBS3 binder. These results are consistent with other studies in the literature [60–62]. At 52 °C, compared to the C binder, the phase angle values of M1, M1.5, M2, M2.5, and M3 decreased by 3.03%, 4.26%, 11.84%, 15.35%, and 17.15%, respectively, while the phase angle value of the SBS3 decreased by 16.42%. At 88 °C, compared to the C binder, the phase angle values of M1, M1.5, M2, M2.5, and M3 decreased by 3.01%, 4.13%, 8.58%, 9.81%, and 10.62%, respectively, whereas the phase angle value of the SBS3 decreased by 5.37%. After 76 °C, the phase angle values converged.

3.3.2. Multiple stress creep recovery (MSCR) test results

MSCR testing was done between 64 °C and 82 °C in a 6 °C increment. Variations of  $J_{nr0.1}$  are shown in Fig. 12 for waste masks and SBS modified binders. In waste mask modification,  $J_{nr}$  values decreased significantly following the enhancement in the additive content. The  $J_{nr}$  values of M1 and M1.5 and M2.5 and M3 were comparable. This restorative effect of the additive content on  $J_{nr}$  rose following the enhancement of the waste mask content. The  $J_{nr0.1}$  values of the binders increased with increasing temperature. This increase occurred significantly after 76 °C in the pure binder. The  $J_{nr0.1}$  value of the SBS3 binder was between the  $J_{nr0.1}$  values of the M1.5 and M2 binders. Generally, the effect of waste mask and SBS on asphalt binder performance is hardness and resilience [58]. The external load will cause smaller peak stress, as the hardness is characterized by an enhancement in the binder modulus. Furthermore, the addition of SBS for asphalt binder’s high-temperature stability enhanced bitumen’s elastic deformation and reduced the permanent deformation. At 64 °C, compared to the C binder,

the  $J_{nr0.1}$  values of the M1, M1.5, M2, M2.5, and M3 decreased by 37.14%, 42.86%, 71.43%, 74.29%, and 80.00%, respectively, whereas the  $J_{nr0.1}$  value for the SBS3 decreased by 42.85 %. At 82 °C, compared to the C binder, the  $J_{nr0.1}$  values of M1, M1.5, M2, M2.5, and M3 decreased by 18.68% 16.09% 58.05% 66.95%, and 68.39%, respectively, whereas the  $J_{nr0.1}$  value of SBS3 decreased by 31.03%. As the temperature increased, the decrease in  $J_{nr0.1}$  values declined compared to the pure binder. After 1.5% mask content, a sudden decrease in  $J_{nr0.1}$  took place with the increase in temperature.

The additive content of the binders and the change in temperature-dependent  $J_{nr}$  values at the high shear stress level (3.2 kPa) are presented in Fig. 13.  $J_{nr}$  values decreased regularly with the enhancement of the additive content in waste mask modification. With the increase in temperature,  $J_{nr3.2}$  values increased, which was greater in waste mask modification with low additive content. Particularly, there was a rapid decrease in  $J_{nr3.2}$  values after 1.5% mask content. SBS3 and M1 binders provided comparable  $J_{nr3.2}$  values. In both modifications, the effect of additives on  $J_{nr3.2}$  was greater at higher temperatures. At 64 °C, compared to the C binder, the  $J_{nr3.2}$  values of M1, M1.5, M2, M2.5, and M3 decreased by 39.53%, 39.53%, 74.42%, 76.74%, and 79.07%, respectively whereas the  $J_{nr3.2}$  value for SBS3 decreased by 44.19 %. At 82 °C, compared to the C binder, the  $J_{nr3.2}$  values of the M1, M1.5, M2, M2.5, and M3 decreased by 22.20%, 35.60%, 60.2%, 61.00%, and 69.00%, respectively, while the  $J_{nr3.2}$  value for the SBS3 decreased by 21.20%.

When the level of stress rose from 0.1 kPa to 3.2 kPa, a rise in  $J_{nr}$  values was observed. This increase was generally larger as the additive ratio increased in both modifications. The  $J_{nr}$  values of the waste mask and SBS modifications were lower than the pure binder at both stress levels. The decrease in the  $J_{nr}$  value indicated that the rutting resistance was high, which is consistent with the studies in the literature [60,63].

The changes in percent recovery (R%) at the 0.1 kPa stress level are presented in Fig. 14. Elastic recovery increased at all temperatures after the enhancement in the additive content in waste mask modification. A steady increase in the recovery percentage occurred after the waste mask content of 1.5% at all temperatures. The percentage of elastic recovery decreased in all additive contents with the increase in temperature. The  $R_{0.1}$  value of the SBS3 was between those of M1 and M2. The comparison of M3 and SBS3 revealed that the M3 showed more flexible behavior than the SBS3. This supported the change in phase angle. At 64 °C, compared to the C binder, the R% values of M1, M1.5, M2, M2.5, and M3 increased by 1.80, 2.00, 2.20, 2.25, and 2.35 times, respectively, whereas the R% value of SBS3 increased by 1.95. At 82 °C, compared to the C binder, the R% values of M1, M1.5, M2, M2.5, and M3 increased by 2.00, 2.00, 2.67, 3.00, and 3.17 times, respectively, the R% value of SBS3 increased by 3.00 times.

The changes in binders’ elastic recovery values along with temperature at 3.2 kPa stress level are presented in Fig. 15. The decrease in R% values concerning temperature for all binders was more evident. As the temperature increased, the R% values decreased. In all binders, R%

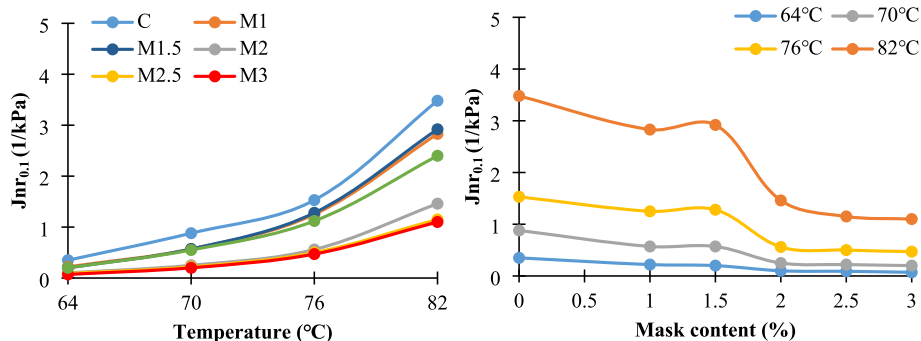


Fig. 12. The differences in the  $J_{nr0.1}$  values of the binders.

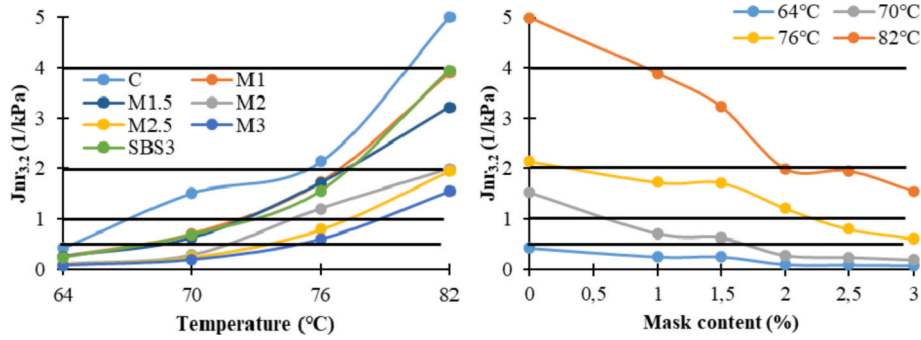


Fig. 13. The variation on the Jnr3.2 values of the binders.

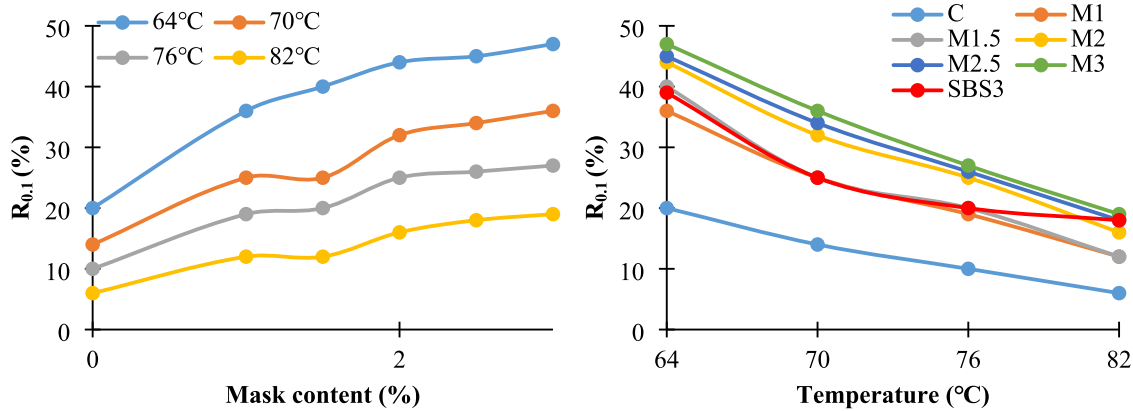


Fig. 14. The variation in R% under 0.1 kPa stress.

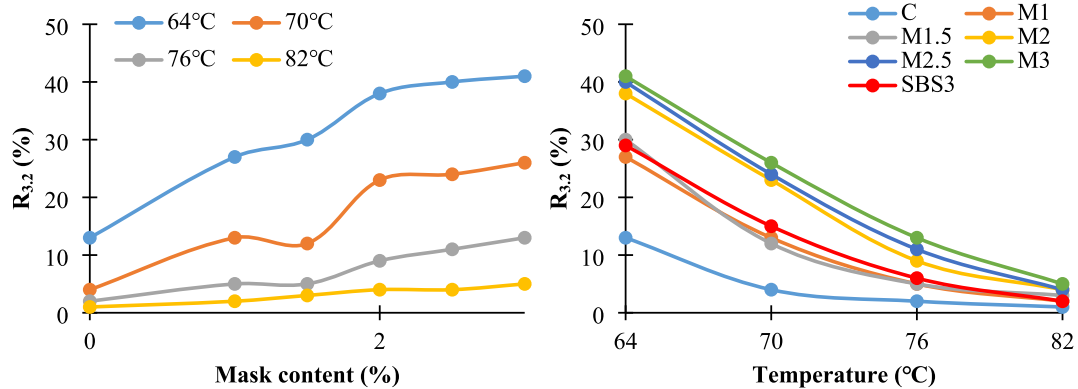


Fig. 15. The variation in R% under 3.2 kPa stress.

values increased as the additive content increased. In particular, a sudden increase in R% values occurred after M1.5. The increment of the level of stress from 0.1 kPa to 3.2 kPa significantly reduced the %R values. At 82 °C, the %R values of M3 and SBS3 decreased from 19% and 18% to 5% and 2%, respectively, as the level of stress rose from 0.1 kPa to 3.2 kPa. While the temperature was enhanced from 64 °C to 82 °C at a 3.2 kPa load level, the flexibility of M3 and SBS3 dropped by 59.57% and 53.85%, respectively. Waste mask modification can better maintain its elastic properties with increasing temperature both at low and high-stress levels.

Changes in  $Jnr_{diff}$  determined in line with AASHTO T350 are given in Fig. 16. The result that the difference between the creep recovery of binders at stress levels 0.1 and 3.2 ( $Jnr_{diff}$ ) was greater than 75% indicates susceptibility to rutting [64,65]. Lower the  $Jnr_{diff}$  values point out higher stress sensitivity.  $Jnr_{diff}$  values of all binders were below 75%,

which proved that all binders met the  $Jnr_{diff}$  requirement. As the temperature enhanced, the  $Jnr_{diff}$  values of all binders were also enhanced. In addition,  $Jnr_{diff}$  values decreased with the enhancement in the waste mask content. Also, a sudden reduction in  $Jnr_{diff}$  values was observed after M1.5. SBS3 was the binder most impacted by the increase in temperature. The  $Jnr_{diff}$  values of binders containing waste masks increased regularly with increasing temperature.

Performance grade (PG) classifications of asphalt binders are shown in Table 3.  $Jnr_{diff}$  values determined in line with T350 revealed good non-recoverable creep compliance performance. The additives used in the present study significantly increased binders' high-temperature performance. Regardless of the modification type, it is durable in extremely heavy traffic conditions at this temperature according to the T350. As the waste mask content in asphalt binders increased, the rutting resistance also increased. M1, M1.5, and SBS3, PG was rated

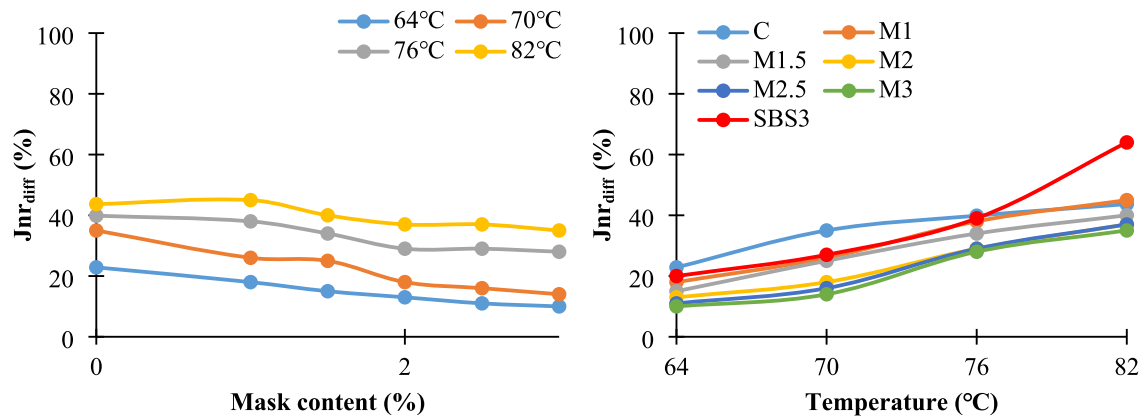


Fig. 16. The variation in the Jnr<sub>diff</sub> values of the binders.

**Table 3**  
Performance grades of the binders according to different methods.

Binder Type and Test Temperature (°C)		G*/sinδ (kPa)		AASHTOT315	Jnr <sub>3,2</sub> (1/kPa)	AASHTO T350	
		Unaged	Aged with RTFO	PG		Jnr <sub>diff</sub>	PG
C	64	3473	1.74E + 04	70	0.43	23	64-E
	70	1658	8541				70-H
	76	872.8	4309				76-H
	82	473.3	2156				-
M1	64	4317.52	1.96E + 04	76	0.26	18	64-E
	70	2078.39	9500				70-V
	76	1023.86	4713				76-H
	82	527.23	2374				82-S
M1.5	64	4739.38	1.96E + 04	76	0.26	15	64-E
	70	2257.94	9702				70-V
	76	1120.05	4814				76-H
	82	587.673	2419				82-S
M2	64	9818.2	3.33E + 04	82	0.11	13	64-E
	70	4705.75	1.67E + 04				70-E
	76	2344.23	8357				76-V
	82	1178.13	4115				82-H
M2.5	64	10,976	3.68E + 04	82	0.1	11	64-E
	70	4878.8	1.86E + 04				70-E
	76	2507.04	8610				76-V
	82	1280.71	4781				82-H
M3	64	12088.2	4.18E + 04	82	0.09	10	64-E
	70	5770.17	2.36E + 04				70-E
	76	2793	9514				76-V
	82	1430.68	6154				82-H
SBS3	64	10,826	1.94E + 04	82	0.24	20	64-E
	70	5317.55	9605				70-V
	76	2764.98	4971				76-H
	82	1462.65	2641				82-S

using four different traffic classifications. As the waste mask content increased, the traffic classification degree decreased. Binders containing waste masks met the “H” traffic level at PG temperature. The SBS3 binder was found to be at the “S” traffic level at PG temperature.

3.4. BBR test results

The BBR test was conducted on modified and pure binders, at -12 °C in line with AASHTO T313. The test results are given in Table 4. A higher creep stiffness (St) indicates that the bituminous material is harder and has less creep compatibility. When bituminous binders’ creep stiffness

decreases, their flexibility increases. The increase in creep stiffness causes thermal cracks in the binders. Accordingly, the creep rate (m) means the low-temperature stress relaxation capability of the bituminous binder. A higher creep ratio points out more preferable stress relaxation capability and bitumen binder’s resistance against cracking at low temperature [66]. The enhancement in the waste mask content led to an increment in creep stiffness. However, all waste mask-modified binders had higher stiffness values compared to the pure binder. Compared to the C binder, the creep stiffness values of M1, M1.5, M2, M2.5, and M3 increased by 1.11, 1.13, 1.39, 1.43, and 1.48 times, respectively. Similarly, the creep stiffness value of the SBS3 rose by 1.14

**Table 4**  
BBR test results.

Properties	C	M1	M1.5	M2	M2.5	M3	SBS3
St (MPa)	97,897	109,072	110,576	135,863	140,675	145,059	111,356
m-value	0,325985	0,324039	0,318971	0,310426	0,309233	0,278739	0,302594

times in proportion to the C binder. The creep stiffness value of the SBS3 binder was between those of M1.5 and M2, as in other tests. M3 provided 1.30 times higher creep stiffness value than SBS3. Hence, the SBS additive offers advantages to thermal cracking. All of the binders achieved the standard as none of them did exceed the 300 MPa creep stiffness upper limit [67]. In both modifications, the m-values decreased consistently with the enhancement in the additive content. C binder provided the highest m-value. Also, the m-values of the M1, M1.5, M2, M2.5, and M3 increased by 0.60%, 2.15%, 4.77%, 5.14%, and 14.49%, respectively, compared to the C connector. Similarly, the m-value of the SBS3 binder increased by 7.18% compared to the C binder. Based on increased creep stiffness and decreased creep rate, it can be concluded that the effect of waste mask modified binder on low temperature cracking performance was minimal. Consequently, it may reduce the resistance to cracking at low temperatures to some extent.

For an accurate evaluation, the “ $\lambda$ ” value is calculated by dividing the creep hardness (St) by the creep rate (m) [44]. Variations in the St/m ( $\lambda$ ) values are shown in Fig. 17. The  $\lambda$  value increased with the increase in the waste mask ratio in the binders. A small  $\lambda$  value is required for elastic behavior at lower temperatures. The  $\lambda$  value of the SBS3 was between those of M1.5 and M2. C binder had the lowest  $\lambda$  value among all binders.

### 3.5. FTIR test results

According to the functional groups detected in the spectra (or according to the active chemical groups), polymer Polypropylene (PP) is used as the raw material in the production of single-use surgical masks. In the production process, PP is melted approximately at 280–300°C and turned into microfibers via processes such as melt-blown and spun-bond. During these processes, no chemical material is added to the PP or the produced microfiber, namely the face mask. Accordingly, there is no chance for the face mask or the waste face mask to become aromatic hydrocarbon. As can be understood from the molecular structure of PP, PP is certainly not aromatic.

Rolling Thin Film Oven (RTFOT) was applied to binders containing pure waste masks and SBS. Short-term aged pure and modified binders were subjected to FTIR-ART analyses and the spectra obtained were presented in a combined way in Fig. 18. Similar transmittance peaks with those of waste mask and SBS found in the present study were also reported by other researchers. All the IR spectra of the specimens demonstrate similarities. This is because PP, which is the raw material for waste face masks, is a petroleum derivative. In other words, they are

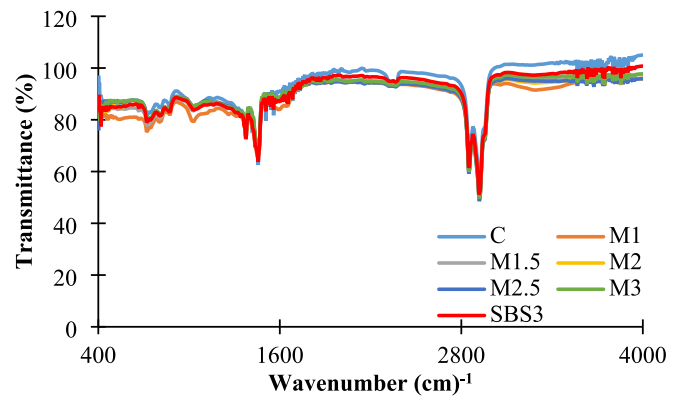


Fig. 18. FTIR spectra of modified asphalt.

materials from the same origin. Accordingly, both the asphalt and the additive materials used in the study have the same functional groups (active chemical groups) thanks to their origin, petroleum.

As seen in Fig. 18, the peak point of 1700  $\text{cm}^{-1}$  indicating the carbonyl group (C = O) and the peak point of 1030  $\text{cm}^{-1}$  indicating the sulfoxide group (S = O) of the binders did not change considerably. However, the 1000–1030  $\text{cm}^{-1}$  wavelength is in the same region where bonds C–C, C–H ve C–O are observed and these bonds exist in the structure of asphalt abundantly. As seen in Fig. 18, the transmittance spectra decreased while the additive content rose compared to the pure binder.

As shown in Fig. 19, the use of both additives paved the way for changes in the indices. C = C, S = O, and C = O index values increased as the SBS additive was used. In the waste masks, an increase occurred in C = C, S = O, and C = O index values, except for M1. As the waste mask additive ratios increased, the C = C and S = O index ratios increased, whereas the C = O index values decreased. M3 had the greatest value in C = C index and sulfur oxide values. There is a significant remarkable increase in oxygen levels for all bitumen modified with waste face masks (PP) for all the modification ratios compared to the pure bitumen, which does not exhibit any trace of oxygen. The presences of heteroatoms, such as sulfur, nitrogen, and oxygen, indicate the polarity of the material because sulfur is the most abundant polar atom in bitumen. The presence of oxygen indicates the formation of ketones, phenols, or carboxylic acid. The concentration of these polar atoms acts as an initiator for the formation of most functional groups as detected by FTIR, some of which

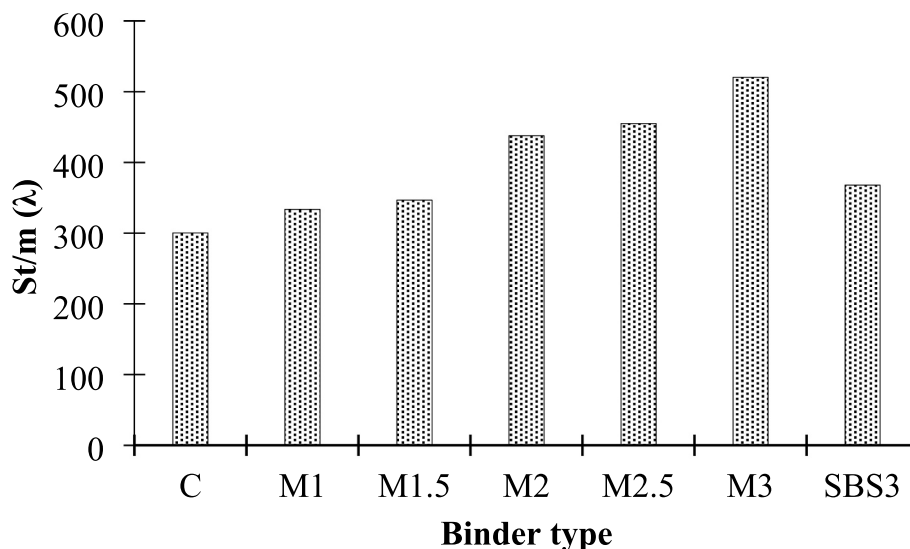


Fig. 17. Changes in St/m-value ( $\lambda$ ) of binders with additive ingredient.



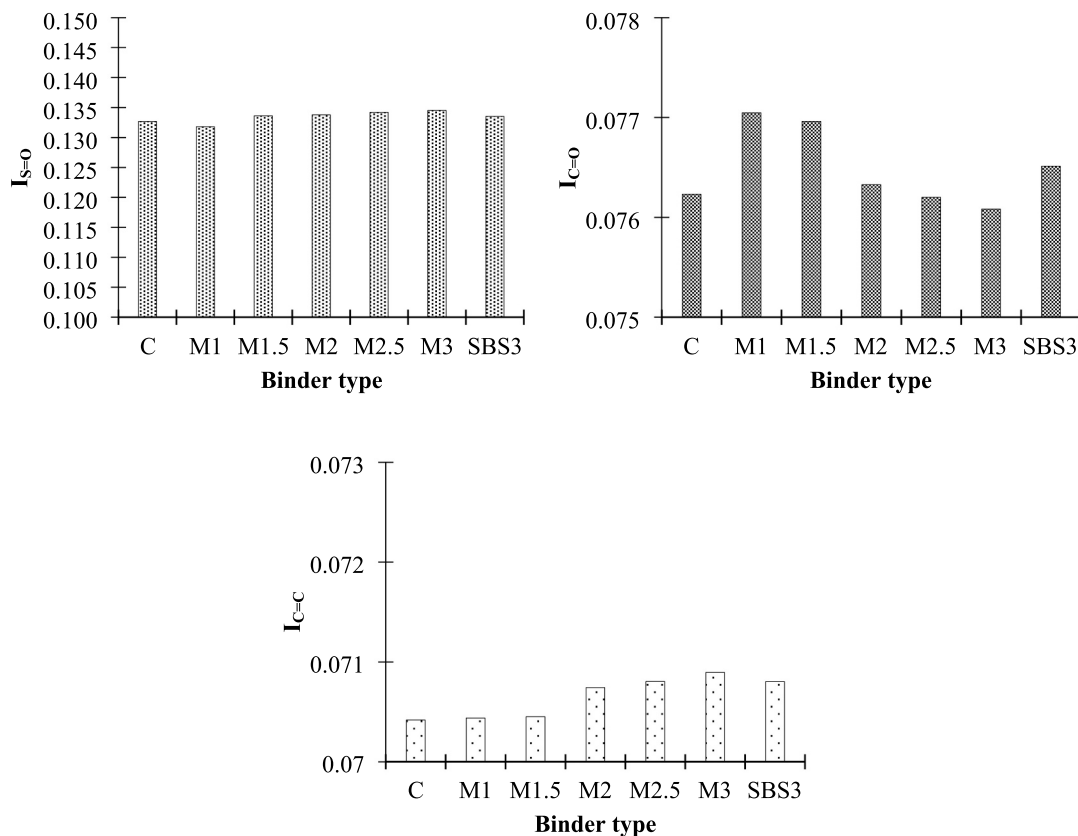


Fig. 19.  $I_{C=C}$ ,  $I_{S=O}$ ,  $I_{C=O}$  index results of binders.

may lead to the deterioration of pavement by aging [18]. Thus, the carbonyl group indicates an increase in the polarity of the bitumen, which leads to greater molecular aggregation or agglomeration [19], which leads to an increase in the viscosity of the bitumen and susceptibility to hardening [17]. The peaks at  $745.85\text{ cm}^{-1}$ ,  $810.76\text{ cm}^{-1}$ ,  $1374.78\text{ cm}^{-1}$ ,  $1455.50\text{ cm}^{-1}$ , and  $1601.34\text{ cm}^{-1}$  were due to the vibration of C = C on the benzene ring and its substitutions [68]. The sulfur oxide values of the M1.5, M2, M2.5, M3 and SBS3 were 1.007, 1.008, 1.011, 1.014, and 1.006 folds much more than the C binder, respectively. The carbonyl value of the SBS3 was 1.006 folds much more than M3. The  $I_{C=C}$  index values of the SBS3 were 1.001 times lower than M3.

#### 4. Conclusions

In conclusion, SBS modified binders and waste masks were produced using melt blending. Conventional (penetration and softening point) and rheological (DSR, MSCR, BBR) features of the prepared modified binders were detected. In addition, the FT-IR test was carried out to research the effect of all additives on the microstructure of the binder. Given the findings of the experimental study, the below conclusions can be suggested:

- The addition of a waste mask and SBS to the pure binder made the physical properties of the binder better. As the waste mask content increased, the penetration value decreased while the softening point value increased. 3% waste mask content increased the physical properties of bituminous binders more than 3% SBS content.
- Since the viscosity values of all binders at  $135\text{ }^{\circ}\text{C}$  were lower than 3000 cP, they fulfill the specification requirement in terms of workability. Waste mask modification was more effective on viscosity than SBS modification.

- Adding a waste mask significantly increased the complex modulus of bituminous binders. 3% waste mask addition provided more shear modulus than 3% SBS addition. In addition, adding a waste mask and SBS to the bituminous binder reduced the phase angle value of the binder and improved its viscoelastic properties. 3% mask modified binder had a more elastic property than 3% SBS modification.
- In waste mask modification,  $J_{nr}$  values dropped significantly with the enhancement in additive content. The stress level rising from 0.1 kPa to 3.2 kPa led to an increase in  $J_{nr}$  values. This increase was generally larger as the additive ratio increased in both modifications. The  $J_{nr}$  values of the waste mask and SBS modifications were less than the pure binder at both stress levels. Waste mask modifications were able to better maintain its elastic properties both at low stress and high-stress levels with increasing temperature. 3%SBS modified binder was the binder most impacted by the temperature rise. The  $J_{nr,diff}$  values of binders containing waste masks increased regularly with increasing temperature.
- Based on increasing creep stiffness and decreasing creep rate, it can be concluded that the effect of waste mask modified binder on low temperature cracking performance was minimal. Thus, the resistance of the waste mask modified binder to cracking at a low temperature slightly decreased. The enhancement in the waste mask content led to a rise in creep stiffness. However, all waste mask-modified binders showed higher hardness values than the pure binder. In both modifications, the creep rate values decreased continuously after the enhancement in the additive content.
- In the use of waste masks, an increase occurred in the C = C, S = O, and C = O index values, except for the 1% mask modification. As the waste mask additive ratios increased, the C = C and S = O index ratios increased, though the C = O index values decreased. Since the raw material of the waste mask is a petroleum derivative, the C = C and S = O index values increase as the waste mask ratio increases. There is a significant increase in oxygen for modified bitumen with

all waste face masks (PP) modification ratios compared to the pure bitumen, which does not have a trace of oxygen. This increases the  $C = 0$  index value.

- It has been determined that binders containing more than 2% waste mask have better performance characteristics than binders containing SBS in terms of physical and rheological properties.

Nowadays, tons of face masks are produced every day to meet the needs of individuals all around the world. Face masks are mostly made of petrochemicals and are considered one of the most hazardous medical wastes today and in the future. This study aimed to eliminate the dangers that waste masks may pose to the environment. It is thought that this study contributes to our world in terms of health, environment, and economy by creating an alternative usage area for waste masks. In future studies, waste masks are planned to be used in hot bituminous mixtures.

## 5. Data Availability

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable requests.

## CRediT authorship contribution statement

**Erkut Yalcin:** Conceptualization, Methodology, Project administration, Writing – original draft. **Ahmet Munir Ozdemir:** Investigation, Writing – original draft, Resources. **B. Vural Kok:** Supervision, Investigation, Writing – original draft, Visualization. **Mehmet Yilmaz:** Supervision, Investigation, Writing – review & editing. **Bahadır Yilmaz:** Writing – review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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