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Dynamic-Mechanic Analysis and Rheological Modelling of Waste Face Mask Modified Bitumen

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ABSTRACT

Due to the Covid-19 global pandemic, the use of face masks has increased considerably in recent years. Used face masks are released into our environment and become a severe environmental threat. Therefore, researchers have focused on the recycling of waste face masks. Recently, studies have been carried out on the use of waste face masks as additives in bituminous materials, but a detailed rheological characterization has not been made. In this study, modified bitumens were obtained by adding 1%, 1.5%, 2%, 2.5%, and 3% waste face mask (WFM). Subsequently, frequency sweep test was performed on modified bitumen samples through a Dynamic Shear Rheometer (DSR). Thus, the viscoelastic behavior of WFM modified bitumen was investigated at different temperatures and loading rates. Performance analysis was conducted with rheological master curves, which were characterized according to analytical and mechanistic models. In this study, rheological evaluations were performed according to the Christensen-Anderson (CA) Model, Christensen-Anderson-Marasteanu (CAM) Model, Sigmoidal Model (SM), and finally, the mechanistic Huet-Sayegh Model (HSM). According to the results, it was determined that WFM significantly increased the rutting resistance of bitumen and performed better at low and high loading rates than the pure bitumen at each WFM ratio.

Keywords: Bitumen, waste face mask, dynamic shear rheometer, rheology, huet-sayegh model.

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1. INTRODUCTION

Recently, the world has been facing a significant crisis due to the coronavirus (Covid-19) pandemic. To reduce the spread of Covid-19 and minimize its infectivity, personal protective equipment (PPE) (mask, gloves, face shield, etc.) is used. Due to the directives of the World Health Organization (WHO) and the rules enforced by governments, the use of masks has become almost proportional to the population. According to the WHO, 89 million masks are required each month to meet the demand due to Covid-19 [1,2]. China has increased the number of masks it produces daily to 14.8 million [3]. Fifty million face masks are produced weekly in Turkey [4]. The use of PPE reduces the spread of the virus; however, since the used equipment is disposable unless planned and adequate waste management is done, it causes environmental pollution and threatens the living spaces. It is estimated that 129 billion masks were discharged into the environment per month in June 2020 [5]. The daily use of masks is estimated to be 3.7 billion in Asia, 951 million in Africa, 891 million in Europe, 781 million in North America, and 591 million in South America. In addition, if expressed as tons per day, 11,308 masks are thrown in Asia, 2,855 in Africa, 2,674 in Europe, 2,346 in North America, and 1,776 in South America [6,7]. For more detailed statistical mask usage information, the study of Nzediegwu et al. can be examined [7]. Face masks are generally produced from polymers such as polypropylene, polyurethane, polyacrylonitrile, polystyrene, polycarbonate, polyethylene, and polyester [8]. This situation significantly contributes to the plastic waste problem in the world.

The first thing that comes to mind as waste material in our environment is plastic derivative materials. Plastic wastes can be partially used as aggregate in building materials. Waste materials are used in many construction materials and systems, from brick production to ground material [9–27]. Asphalt mixtures consist of non-renewable resources, especially binder. Thus, it is environmentally crucial to improve its properties or partially use the waste materials in the mixture. Bituminous binders are modified with various additives. Although polymers such as SBS, SEBS, and EVA are commonly preferred, organic and inorganic wastes are also used. Performance improvements can be achieved by using both bituminous binder and plastic waste in the mixture. In their study, Verapalumbo et al. used different percentages of waste plastic in bitumen and determined that waste plastic improved aging resistance, elasticity, and strength [28]. In another study, Genet et al. modified bitumen by adding waste LDPE plastic. Consequently, the mixture prepared with LDPE-modified bitumen presented a 33% higher stability value than the pure mixture [29]. Haider et al. investigated the moisture damage properties of mixtures obtained using waste plastic materials. Test results showed that adding high-density polyethylene increased the adhesion properties and moisture damage resistance [30]. Li et al. investigated the usability of waste plastics in asphalt mixtures as an anti-stripping agent. The results showed that the waste plastic increases the moisture resistance of the mixture; thus, it can be used as an anti-stripping agent [31]. In another study, researchers investigated the mechanical and thermal behavior of the bitumen by adding two different types of waste polyethylene. The results showed significant improvements in high-temperature performance parameters such as rutting compared to commercial polymer modified binders [32]. Yu et al. emphasized that energy savings can be achieved by using waste plastics in mixtures, and they examined the performance of direct-input waste plastic microscopically. According to the results, the direct-input waste plastic modifier can achieve micron-level dispersion in the bitumen [33]. Dalhat and Al-Abdul Wahhab investigated the effects of different plastic types such as polypropylene, high- and low-density polyethylene (PP, HDPE, and LDPE)-recycled plastic wastes (RPW) on the viscoelastic properties of bitumen. It has been observed that all plastic wastes meet the specification limits and give better results than pure bitumen [34].

WFMs, resulting from the Covid-19 pandemic, has significant adverse effects on our environment. This case has led scientists to investigate the waste management of WFMs. Various studies have been carried out recently on the evaluation of waste masks released due to the Covid-19 pandemic in asphalt materials. Wang et al. added waste face masks to the asphalt mixture in their study and concluded that high resistance to rutting resistance was obtained. When the waste mask addition rate was 1.5%, the rutting depth value of the mixture decreased from 3.0 mm to 0.93 mm [35]. Zhang et al. carried out a study involving the use of waste masks with waste cooking oil. It was determined that the addition of the mask significantly increased the high temperature resistance, but decreased the low temperature performance. It was concluded that the use of waste cooking oil can relatively eliminate the low temperature disadvantage [36]. In another study, Zhao et al. obtained modified bitumen by adding waste masks to binder in various proportions. As a result of the rheological and physical experiments on pure and modified bitumen, it was determined that the addition of mask increased the complex modulus values of the bitumen, but decreased the phase angle values. In addition, as a result of imaging analysis, it was seen that asphalt and waste mask additive interacted well and formed a homogeneous mixture [37]. Yalçın et al. investigated the effect of waste mask addition on the performance properties of bitumen. It was observed that the rutting parameters increased as a result of the addition of masks at different rates by bitumen weight. In addition, the authors emphasized that mask addition of more than 2% gave better results than 3% SBS [38].

In the previous study of the research team, the effect of mask addition on the rheological behavior of the material was investigated with various experiments [38]. Rheology can be analyzed in two classes: experimental and theoretical. While experimental rheology explains the relationship between stress and strain rate in the laboratory environment, theoretical rheology explains the behavior of the material with mathematical models independent of its microscopic structure. For non-newtonian materials, these mathematical equations become more complex [39,40]. Since the waste face masks used in the study are polymer materials and polymer materials have non-newtonian character, their effects on bitumen behavior should be examined rheologically in detail. As seen in the literature, no detailed rheological characterization has been found in the studies on the addition of masks to bituminous materials. Based on this, a detailed rheological modeling and characterization of waste mask modified bitumen was made in this study. Waste face masks were divided into small pieces and added to bitumen at 1%, 1.5%, 2%, 2.5%, and 3% ratios. Frequency sweep test was applied through Dynamic Shear Rheometer to simulate different temperatures and loading rates. From the data, master curves were obtained to expand the frequency range further and analyze a wide frequency range. Afterwards, these master curves were interpreted with various rheological models.

2. MATERIALS AND METHOD

2.1. Bitumen

B 50/70 bitumen with a density of 1.015 g/cm^3 was utilized as a pure binder. The bitumen used in the study was obtained from TÜPRAŞ Batman Refinery. Conventional binder experiments were performed on the bituminous binder, including penetration, softening point, and rotational viscometer (RV). RV test was performed at 135°C and 165°C. The test results and the properties of bitumen are presented in Table 1.

Table 1 - Properties of B50/70 bitumen

Test	Unit	Standard	Results
Penetration	0.1 mm	AASHTO T 49	57
Softening Point	°C	AASHTO T 53-06	56.1
Flash Point	°C	TS EN ISO 2719	245
Density	g/cm^3	ASTM D70-18a	1.015
Solubility	Percentage	TS EN 12592	100
Rotational Viscosity			
135°C	cP	AASHTO T316	675
165°C	cP	AASHTO T316	175

2.2. Waste Face Mask (WFM)

Disposable face masks are manufactured using polymers including polyurethane, polyacrylonitrile, polycarbonate, polystyrene, polypropylene, polyester, polyethylene [41]. These masks consist of 3 layers: the outer layer (made up of nonwoven fibers that are mostly colorful and water-resistant), middle layer (i.e. melt-blown filter), and inner layer (i.e. soft fibers). The outer layer is composed of spunbond or thermo-nonwoven polypropylene fabric [42]. 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 spunbond non-woven propylene, PES (polysulfone) or their mixtures. The middle layer has a high fiber density and is a fluffy layer in order to ensure better filtration. The inner layer is composed of spunbond 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. 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 up to 72 hours following direct exposure [43]. For this reason, after the collected waste masks were kept in an isolated environment for 96 hours, they were completely ground except for the metal strips in the masks. The dimensions of the ground masks were 2-4 mm on average (Figure 1).

Figure 1 - Waste face mask (WFM) used in the study

2.3. Modification Process of Bitumen

In the study, modified bitumen was obtained by adding 1%, 1.5%, 2%, 2.5% and 3% WFM by weight of pure bitumen. The modification started by heating the pure bitumen at 180±5°C for half an hour to liquefy. Afterwards, the liquefied bitumen was poured into a 500 g metal mixing pot, which was kept at 180°C. Pure bitumen and WFM were mixed for 1 hour at 1000 rpm to obtain the modified bitumen [38].

2.4. Frequency Sweep Test via Dynamic Shear Rheometer (DSR)

Viscoelastic responses of the bituminous binder are characterized by determining the complex shear modulus (G*) and phase angle (δ) through the DSR test. G* is a measure of the resistance to deformations caused by repeated shear stresses in the binder. The complex shear modulus is defined by two parts: elastic modulus (G') and viscous modulus (G'') [44]. These parts are associated with the G* and δ values. The phase angle equals the time difference between the applied stress and the resulting deformation. The material's behavior is assumed to be completely elastic when the phase angle is 0° and downright viscous when it is 90° [45] (Figure 2).

The frequency sweep test can simulate the speed of a vehicle moving on asphalt pavement. A loading frequency of 10 Hz corresponds to a speed of 60 km/h, while a loading frequency of 15 Hz corresponds to a speed of 90 km/h. The complex modulus and phase angle values vary significantly with temperature and frequency [46]. In this study, DSR tests were carried out on pure and WFM modified bitumen samples at four different temperatures (40°C, 50°C, 60°C, 70°C) and ten different frequencies (0.01-10Hz). Thus, the effect of waste mask addition on the viscoelastic character of bitumen was determined under different frequencies and temperatures. The sample geometry was determined to be 25mm in diameter and 1mm in height.

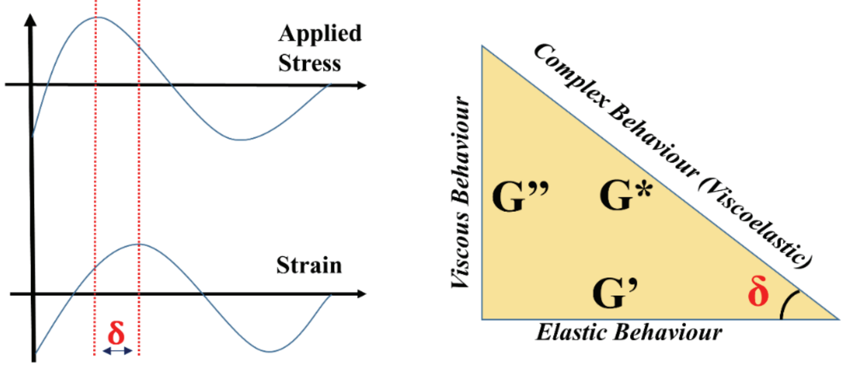


Figure 2 - Viscoelastic behaviour of bitumen

2.5. Christensen-Anderson (CA) Model

Cristensen and Anderson developed an empirical-analytical model in 1992 under the Strategic Highway Research Program (SHRP) to describe the rheological behavior of asphalt. In this model, presented in Equation 1, the rheological behavior is explained in terms of G* values as a function of the frequency applied to the bitumen. Although the model's primary purpose is to characterize pure bitumen, it has recently been used to describe the behavior of modified bitumen. Numerous studies have been conducted with the CA model [47–49]. CA model parameters are beneficial for analyzing conditions such as the effect of the additive used for modification, the effect of aging, and the effect of experimental inputs. Model parameters have physical meanings; thus, more meaningful evaluations can be made. A graphical representation of the CA model is given in Figure 3. It can be said that Figure 3 is also valid for the CAM model that is to be mentioned in Section 2.6.

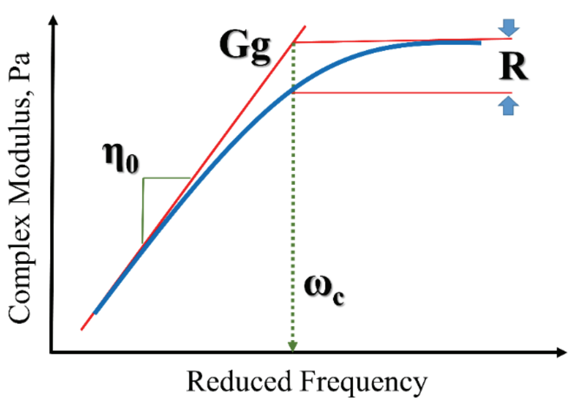


Figure 3 - Graphical representation of CA Model

$$|G^*| = G_g\left[1 + (\frac{\omega_C}{\omega})^{\frac{log2}{R}}\right]^{\frac{-R}{log2}} \quad (1)$$

where G* is the complex shear modulus (Pa); G_g is the maximum G* (glassy modulus) (Pa); ω_c is the crossover frequency at the cross point; ω is the reduced frequency; R is the rheological index.

ωc represents the frequency at which the viscous and elastic modulus is the same. Furthermore, this point is where the viscous asymptote and the glassy asymptote overlap. ωc characterizes the overall hardness of bitumen. R is the difference between the complex modulus at ωc and the intersection asymptotes, which is also called shape factor. The increase in the R value indicates that the viscous properties of the binder decrease and become brittle at intermediate loading times and temperatures.

2.6. Christiensen-Anderson-Marasteanu (CAM) Model

The CAM model is an enhanced version of the CA model. CA model was modified to improve fitting performance at lower and higher frequency ranges, resulting in the CAM model. Many successful studies of the rheological characterization of binders use the CAM model [50–53]. The CAM model is presented in Equation 2:

$$|G^*| = G_g\left[1 + (\frac{\omega_C}{\omega})^{v}\right]^{\frac{-w}{v}} \quad (2)$$

where v is the fitting parameter (equals log2/R seen in Equation 1); w is the parameter that deals with how fast or slow |G*| data. For example, when the frequency approaches zero, a bitumen with w>1 will reach the 90° asymptote faster than a bitumen with w<1.

2.7. Sigmoidal Model (SM)

The sigmoidal model is one of the most common models used to describe the rheological properties of bituminous binders. G* was characterized through SM as a function of frequency, as in the previously mentioned models. The SM is relatively simple compared to complex models, yet it adapts with sufficient accuracy. SM is given in Equation 3:

$$log|G^*| = v + \frac{a}{1+e^{\beta+\gamma(\log(\omega))}} \quad (3)$$

where G* is the complex modulus; ω is the reduced frequency; v is the lower limiting modulus; α is the difference between upper and lower horizontal asymptote; β is the factor that controls the horizontal position of the inflection point; γ is the slope of the curve.

2.8. Huet-Sayegh Model (HSM)

In addition to empirical models, mechanistic models can describe the complex shear modulus thanks to their physical elements [54]. Maxwell, Kelvin, and Burger models are the main mechanistic models explaining the behavior of asphaltic materials, generally viscoelastic materials. The Huet-Sayegh model is a mechanistic model with non-classical linear viscoelastic elements whose structural properties are defined by fractional derivatives. Fractional derivatives are used in solving physical problems and describing the rheological behavior of viscoelastic materials [55,56]. The structure of the HSM is shown in Figure 4, and the model equation is given in Equation 4 [57].

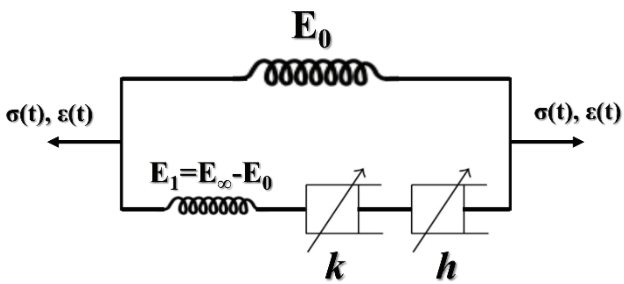


Figure 4 - The Huet-Sayegh model

The Huet-Sayegh model consists of two parallel branches, an elastic spring (E_0), and a branch consisting of three elements connected in series. While the elastic spring (E_0) represents the long-term elastic modulus when the frequency is zero, the other elastic spring (E_1) is the difference in instantaneous elastic modulus E_1 (frequency is infinite) and long-term modulus E_0 and two parabolic dashpots.

$$E^* = E_0 + \frac{E_1 - E_0}{1+\delta(i\omega\tau)^{-k}+(i\omega\tau)^{-h}} \tag{4}$$

where ω is the reduced frequency; E_0 is the static modulus (ω→0); E_1 is the glass transition modulus (ω→∞); k and h are paremeters (0<k<h<1); δ is a dimensionless constant and τ is the characteristic time; and i^2= -1.

3. EXPERIMENTAL STUDY

DSR tests were applied to pure and WFM modified bitumen at four different temperatures (40°C, 50°C, 60°C, and 70°C) and ten different frequencies in the 0.01-10 Hz frequency range. Afterwards, the results were processed according to the time-temperature superposition (TTSP) principle, and master curves were obtained at 40°C reference temperature (Fig. 5(a)). Furthermore, G* values at four different frequencies are presented in Figure 5 (b). Figure 6 shows a black diagram plotting phase angle values versus complex modulus values.

Figure 5 (a) shows that the complex shear modulus values increased with increasing frequency (loading speed). As the WFM content increased, the complex modulus values of bitumen increased. While the effect of the mask was more pronounced at low frequencies,

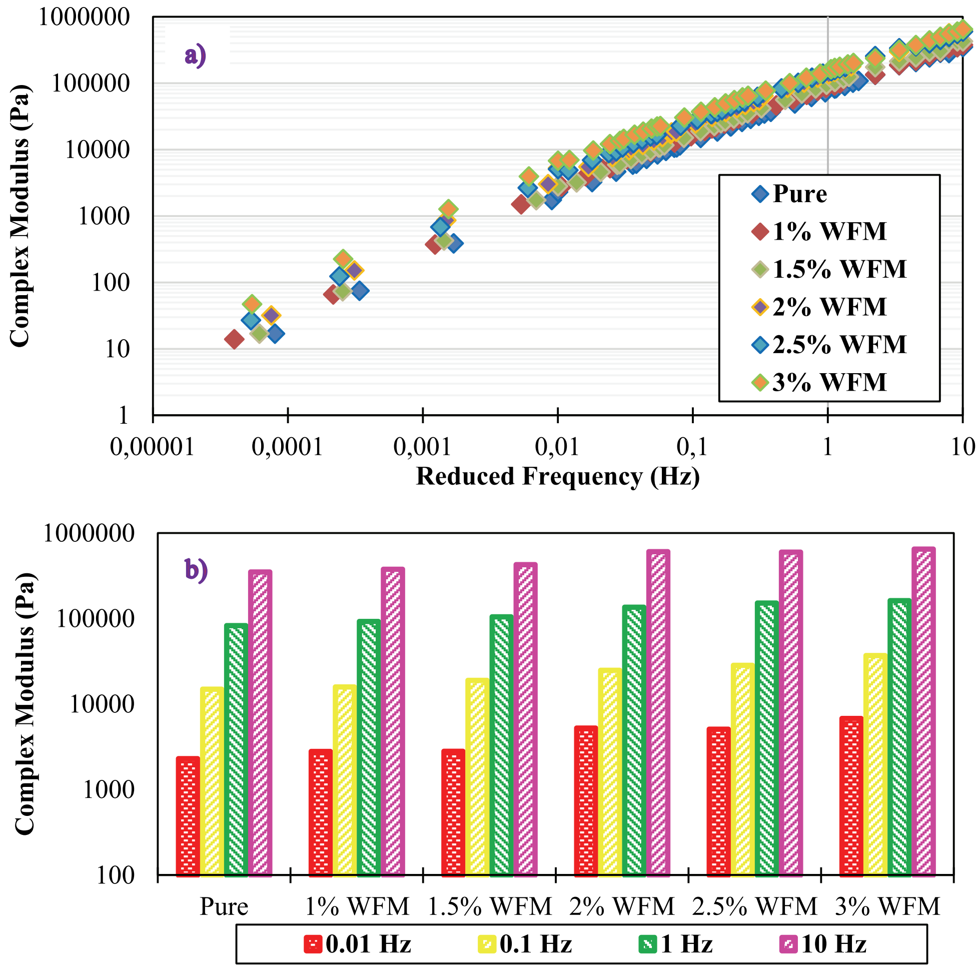


Figure 5 - a) TTSP master curves of pure and WFM modified asphalt binders, b) complex modulus values at 0.01, 0.1, 1, and 10 Hz

the effect of WFM content decreased at high frequencies, and the complex modulus values became closer. Since both the horizontal and vertical axes are logarithmic in the graphs, the values are close, although the differences between the binders are apparent. Furthermore, as the amount of waste mask increased, the difference in complex modulus values became evident. The pure binder gives the lowest complex modulus value. As WFM increases, the overall resistance of the binders against deformation when subjected to shear load also increases. Total resistance to deformation was seen at most 3% of the WFM binder. To efficiently evaluate the complex modulus values of bitumens, master curve G* values at frequencies of 0.01, 0.1, 1, and 10 Hz were given in Figure 5 (b). As seen in Figure 5 (b), the complex modulus values increased as the frequency and WFM content increased. The changes in the G* values of binders are visible when the frequency changes. When Figure 5 is examined, compared to the pure binder, the G* values of the other binders increased more, especially after 2% WFM.

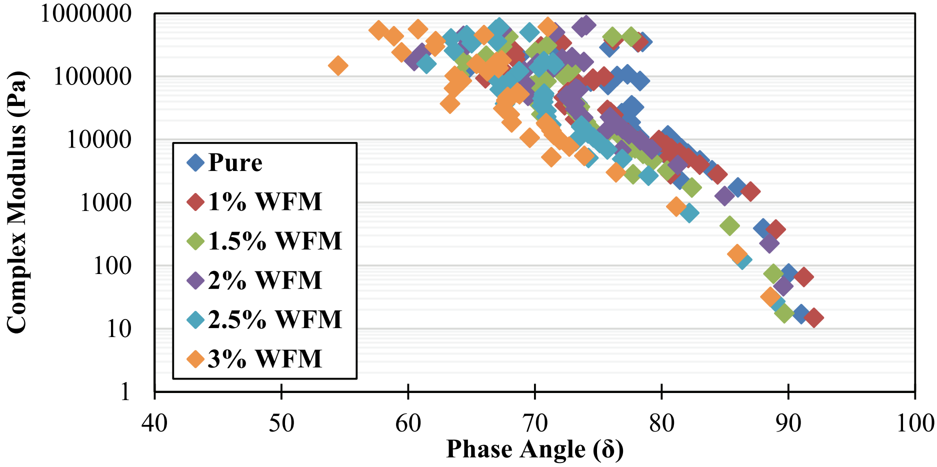


Figure 6 - Illustration of complex modulus-phase angle relationship (black diagram)

The black diagram, generated by data obtained at 40-70ºC, is given in Figure 6. The waste mask modification shows that curves create too much clutter and do not form a proper "S" shape, so it is a thermo-rheologically mixed material; therefore, it is a complex material. High phase angle values show that the time-temperature superposition is broken, and the material is transformed into a thermo-rheologically complex structure. At low phase angle values, i.e., at low temperatures, the waste mask modifications shift slightly to the left of the diagram relative to the pure binder, meaning they are slightly more elastic. Low phase angle and high G* values indicate that binders behave more elastic. When Figure 6 is examined, the phase angle values have increased with the decrease in the G* values in the pure bitumen. Considering the modified bitumens, the phase angle values have reached the lowest level, and the phase angle values have increased regularly, especially in G* values of 1.0E + 4 Pa and 1.0E + 5 Pa, especially as the WFM content increases. In WFM modified bitumen, the G* values increase up to 1.0E+5 Pa after decreasing phase angle values. The phase angle value in the 3%WFM binder was around 60-70°.

4. RESULTS AND DİSCUSSİONS

4.1. Christiensen-Anderson (CA) Model results

The analysis of the master curves of asphalt binders pure and containing 1%, 1.5%, 2%, 2.5%, 3% WFM with CA Model is given in Figure 7. Also, all CA Model curves are presented collectively in Figure 8. Rheological model parameters are given in Table 2.

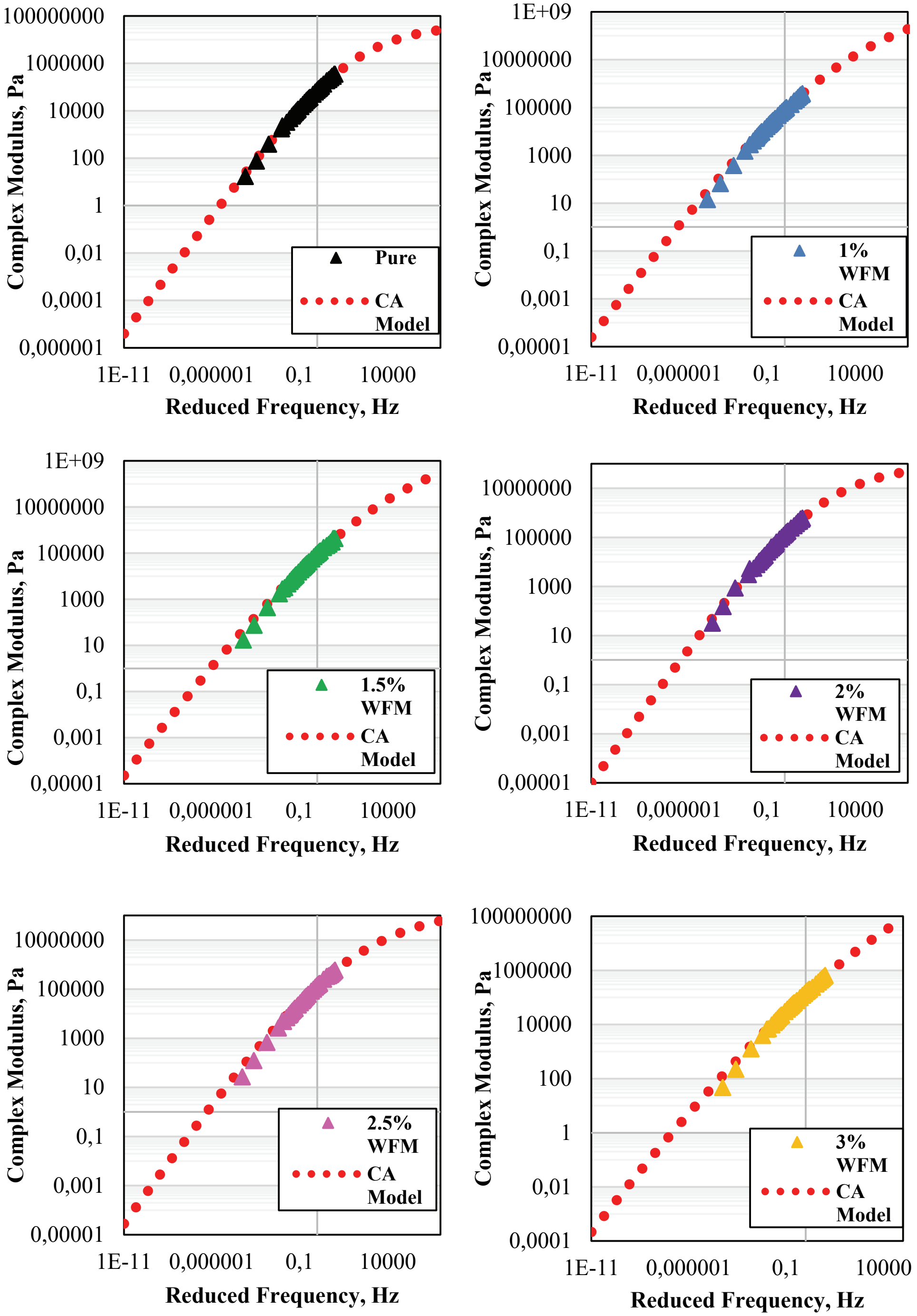


Figure 7 - CA model results of pure and 1, 1.5, 2, 2.5, 3% WFM modified asphalt binders

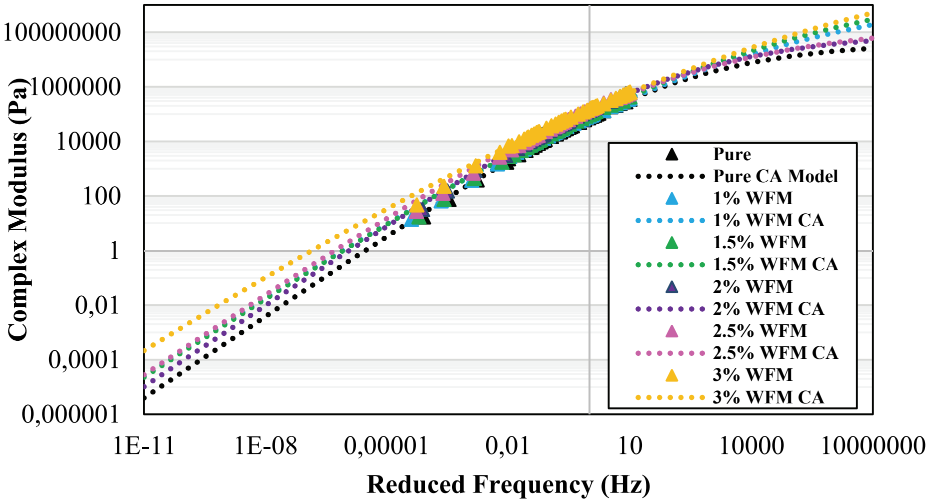


Figure 8 - Illustration of whole CA model curves

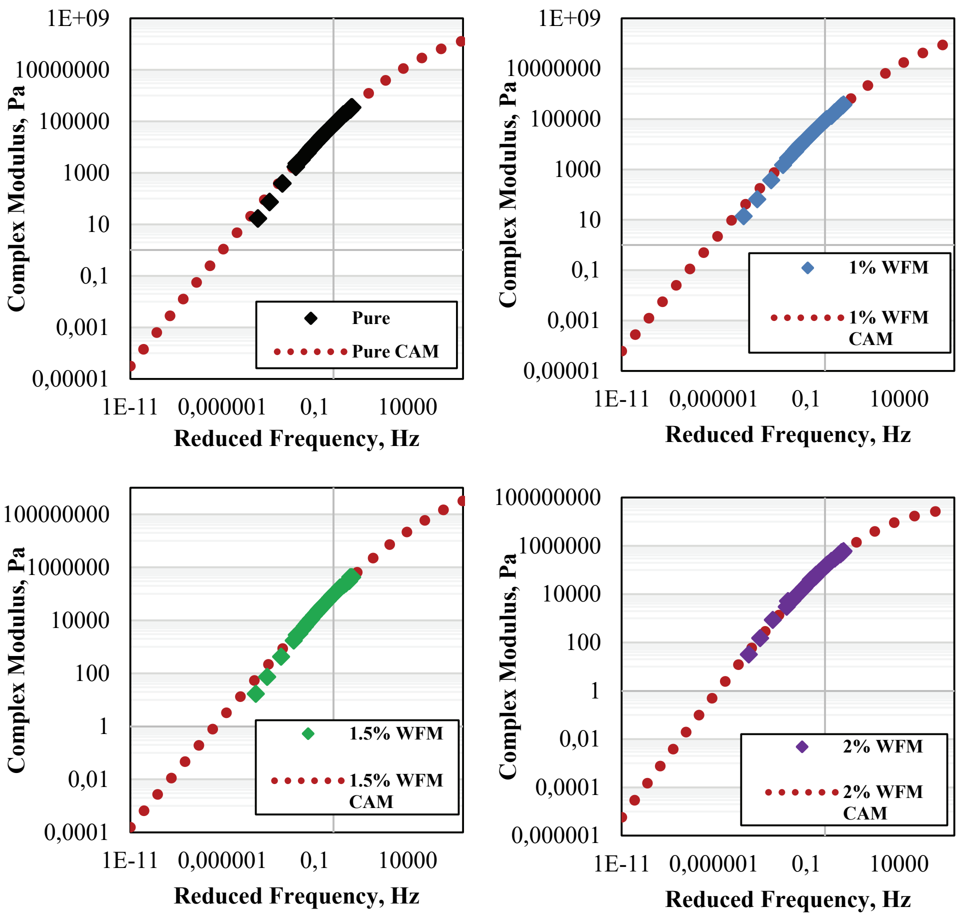
Table 2 - CA model parameters of pure and modified binder samples

	Gg	ωc	R	Coefficient of determination
Pure	$1x10^9$	104.89	2.611	0.98
1% WFM	$1x10^9$	1398.92	2.360	0.99
1.5% WFM	$1x10^9$	3290.97	2.186	0.96
2% WFM	$1x10^9$	3666.48	2.079	0.97
2.5% WFM	$1x10^9$	4098.21	1.544	0.97
3% WFM	$1x10^9$	4294.23	0.647	0.99

When Figure 7 is examined, it is clearly seen that the master curves have been successfully fitted with the CA model (R^2>0,95). The pure binder is closer to the model curve in the initial frequency values, but there is little deviation in the other binder contents. This case led to the difference in CA model parameters. Thus, rheological characterization between pure and modified binders was possible. In Figure 8, whole master curves and CA model curves were given together. According to Figure 8, the differentiation and modification effect of very low and very high frequency values can be clearly seen. In the CA model curve of 3% WFM modified bitumen, separation is evident at the lowest and highest frequency values. CA model parameters was given in Table 2. Various studies have been carried out to obtain 1 GPa at shear strength of the glassy modulus (Gg), and it has been determined that most binders offer this value. In previous studies, it has been suggested to fix the glassy modulus (Gg) value to 10^9. Most bitumen has a Gg value of 10^9. In this study, the Gg value was fixed to 10^9, and other parameters (ωc and R) were released. ωc is a binder-specific value and can be defined as a measure of the overall consistency of bitumen. When the crossover frequency (ωc) values are examined (Table 2), it is seen that ωc also increases with the increase in the WFM rate. This is interpreted as the modification mechanism is formed, and the material hardens with the addition of WFM, confirming the penetration and softening point results. The rheological index (R) can be used to describe the shape of the master curve. R is associated with the width of the relaxation spectrum [58]. In addition, this parameter is a beneficial tool because of its sensitivity to bitumen hardness variations in loading time/frequency. Even small changes in bitumen hardness due to aging and chemical changes produce significant changes in R values [52]. In Table 2, it was seen that R values decreased as the amount of WFM increased.

4.2. Christiensen-Anderson-Marasteanu (CAM) Model results

Figure 9 shows the CAM Model curves for pure and WFM modified asphalt binders. In Figure 10, a collective representation of all CAM curves is presented. Also, the CAM Model parameters are given in Table 3.



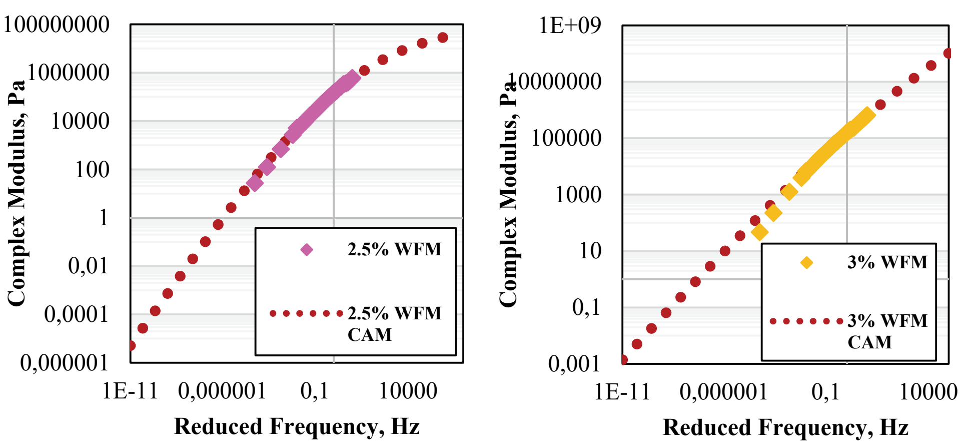


Figure 9 - CAM model results of pure and 1, 1.5, 2, 2.5, 3% WFM modified asphalt binders

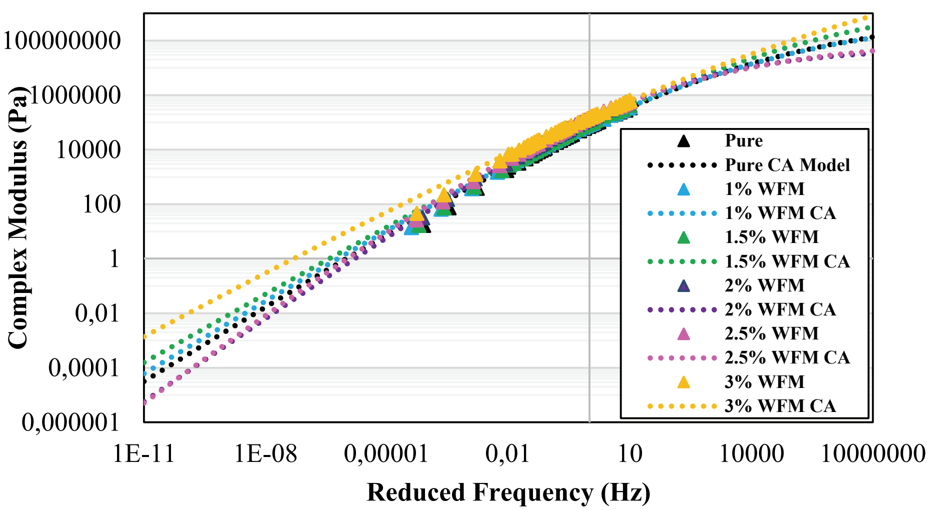


Figure 10 - Illustration of whole CAM model curves

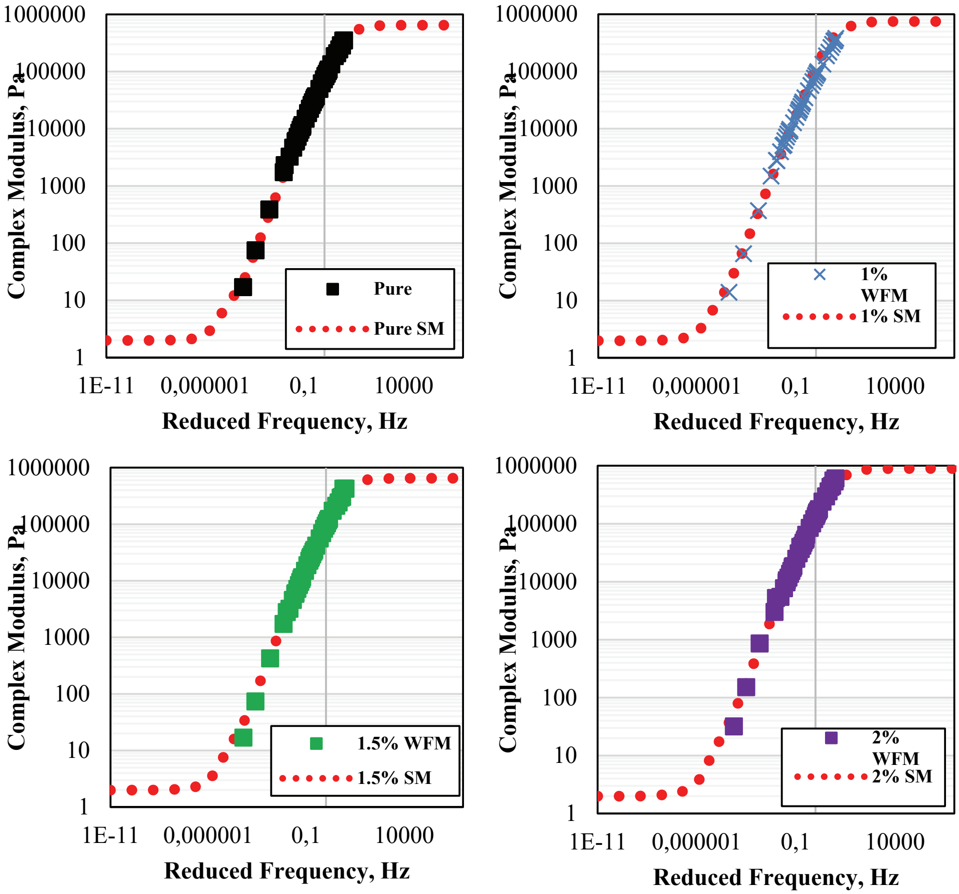
Table 3 - CAM model parameters of pure and modified binder samples

	Gg	ωc	w	v	R^2
Pure	$1x10^9$	3512,17	1,023	0,138	0,99
1% WFM	$1x10^9$	3695,97	0,900	0,136	0,99
1.5% WFM	$1x10^9$	8049,10	0,846	0,133	0,98
2% WFM	$1x10^9$	49067,21	0,877	0,135	0,99
2.5% WFM	$1x10^9$	94487,14	0,798	0,141	0,97
3% WFM	$1x10^9$	170603,01	0,818	0,139	0,96

4.3. Sigmoidal Model (SM) results

SM curves of pure and WFM modified asphalt binders are given in Figure 11. Figure 12 was plotted to investigate the rheological changes with increasing additive ratio. Also, SM parameters are given in Table 4.

In fact, the sigmoidal model is designed to define the dynamic modulus of asphalt mixtures. However, it is also widely preferred for binders. The SM model does not consistently achieve the desired performance in the master curve characterization of modified bitumens. Figure 11 shows the sigmoidal model curves of pure and 1%, 1.5%, 2%, 2.5%, and 3% WFM modified binder samples. When Figures 11 and 12 are examined, the formation of the Sigmoidal model in the form of "S" has been successful, and the complex modus values are highly accurate (min. R^2 = 0,97). According to Table 4, the value "ν" is negative for all samples. This case is expected. A negative value of "ν" means that complex modulus values are too low in low frequency and high-temperature conditions. Except for 1.5% WFM, the β value for whole samples is higher than the pure bitumen. This is attributed to the formation of a modification mechanism and the hardening of the material. The "γ" values are negative and almost identical in all samples. This indicates that the addition of WFM does not change the direction of the master curve.



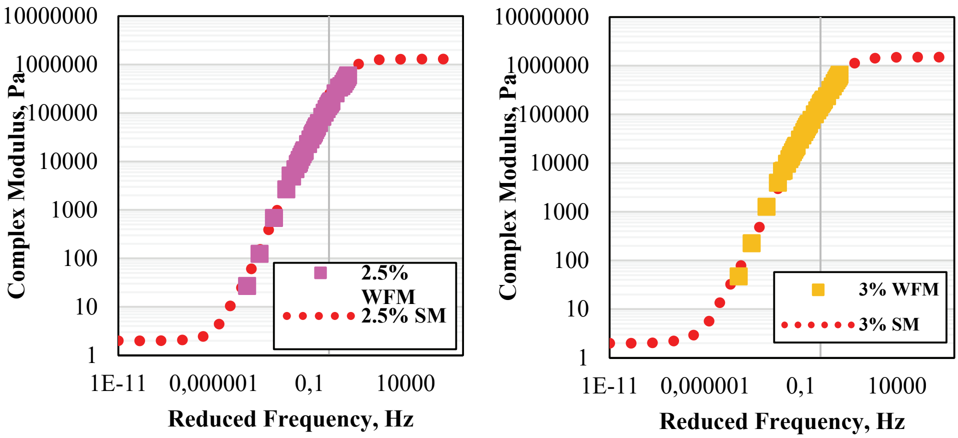


Figure 11 - SM model results of pure and 1, 1.5, 2, 2.5, 3% WFM modified asphalt binders

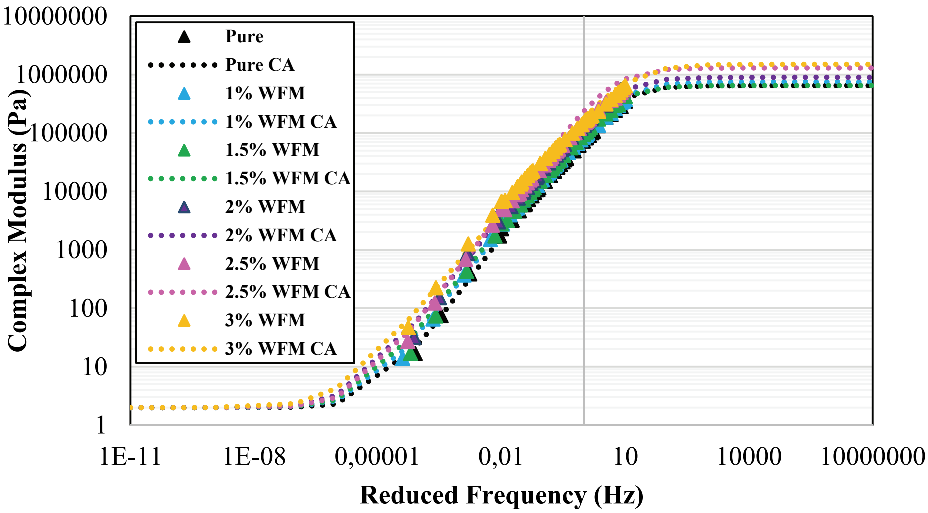


Figure 12 - Illustration of whole SM model curves

Table 4 - Sigmoidal model parameters of pure and modified binder samples

	ν	a	β	γ
Pure	2	650000	1,40	-2,15
1% WFM	2	750000	1,71	-2,05
1.5% WFM	2	650000	1,53	-2,05
2% WFM	2	900000	1,88	-2
2.5% WFM	2	1300000	2,11	-2,1
3% WFM	2	1500000	2,00	-1,9

4.4. Huet-Sayegh Model (HSM) results

Master curves of pure and 1%, 1.5%, 2%, 2.5%, and 3% WFM added bitumens were fitted to the mechanistic Huet-Sayegh model. The results are given in Table 5 and Figure 13.

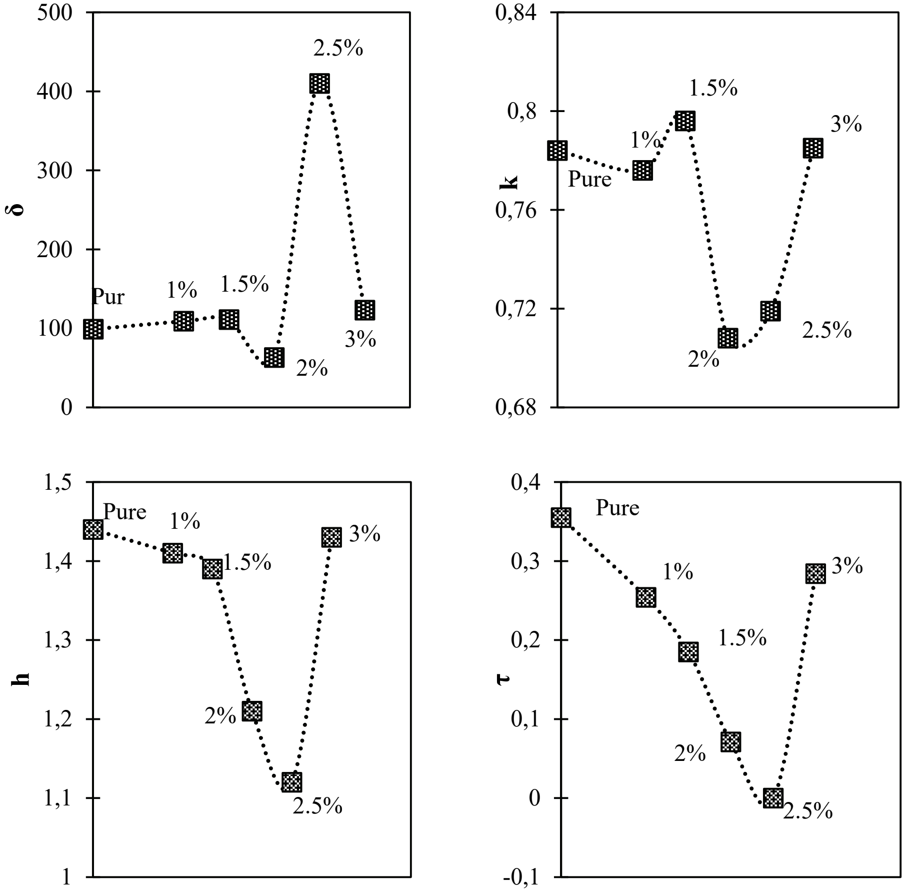


Figure 13 - Huet-Sayegh model parameters with different WFM contents

Table 5 - Huet Sayegh mechanistic model parameters (Reference Temperature = 40°C)

	E0	E1	δ	k	h	τ
Pure	$2{,}91x10^{-31}$	3,70E+06	99,18	0,784	1,440	0,355
1% WFM	$8{,}76x10^{-36}$	5,70E+06	109,5	0,776	1,406	0,254
1.50% WFM	$4{,}67x10^{-39}$	8,36E+06	111,89	0,796	1,398	0,185
2% WFM	7,17	1,51E+09	224,40	0,708	1,207	0,071
2.50% WFM	1,31	1,98E+09	410,064	0,719	1,121	5,04E-05
3% WFM	$5{,}76x10^{-38}$	2,15E+09	123,282	0,785	1	0,284

Some assumptions can be made for E_0 and E_1 values. It is known that there are studies in the literature where E_0 is equal to zero and E_1 is equal to 1 GPa. In this study, both values were released, the fitting process was performed, and other model parameters were obtained. When Table 5 is examined, the static modulus (E_0) values are almost zero for all bitumen samples. As the angular frequency goes to infinity, the glass transition module E_1 is mentioned. It was observed that E_1 values increased with the use of WFM, and this was interpreted as an indication that the bitumen hardened and its strength increased. "k" and "h" are two crucial parabolic creep parameters in viscoelastic characterization. According to Table 5, the k and h parameters are almost the same for all binder samples. This result shows that the modification process does not cause any change in the shape and direction of the master curves. If explicitly evaluated, it is possible to interpret the decrease in h value as a decrease in viscous properties [59]. An increase in δ indicates that the material has hardened. When the results were examined, the increase in the WFM ratio increased the δ values, confirming the traditional binder test results. The reduction in the 3% WFM sample is considered to be an error due to a concentration in the data.

5. CONCLUSIONS

In this study, the usability of waste face masks (WFM), which has emerged due to the Covid-19 pandemic that recently affected the world, was investigated as a bitumen additive. WFMs were divided into small pieces and afterwards added to the bitumen at the rates of 1%, 1.5%, 2%, 2.5%, and 3%. The modified bitumen samples were subjected to frequency sweep test through Dynamic Shear Rheometer (DSR). After the DSR test, rheological characterization was conducted using analytical and mechanistic models. The results were given as follows:

- Compared to the pure binder, higher G* values were obtained by adding WFM. Furthermore, a steady increase was observed in direct proportion to the PDG content. The addition of WFM resulted in more rutting-resistant asphalt binders.
- Master curves have been successfully obtained to evaluate the response of the bitumens at very high and very low frequency values in a broader range. With the increase in frequency, higher G* values were obtained. The increase in WFM content showed a higher complex modulus value at almost every frequency compared to the pure binder.
- Four different rheological models (CA, CAM, SM, HSM) were successfully applied to the results (R^2>0,98). To summarize;
- According to the CA model, the crossover frequency (ωc) values increased with the increase in WFM content. This indicates that the bitumen hardening occurs due to the modification process. When the CAM Model parameters were examined, it was determined that adding WFM increased the inclination to elastic behavior. According to the SM Model results, it can be said that no negativity has occurred in the shape and direction of the master curves. The HSM results showed that mechanistic models could successfully apply to WFM modified bitumen.
- When the models are compared among themselves, it is seen that for the CA and CAM Models, both provide highly accurate results (R^2>0.96). In addition, the ωc value increased with the increase in the additive ratio in both models. When the CA Model results were analyzed, it was observed that the R value decreased with the use of

additives, which was interpreted as the additive caused hardening of the bitumen. Based on this, it is interesting that the highest value of "w" among the CAM Model parameters was obtained in pure bitumen. A higher value of "w" means that it approaches 90°, in other words, the viscous asymptote, faster. In other words, it can be said that pure bitumen is less prone to elastic behavior.

- When the sigmoidal model results are compared with other rheological models, it is seen that it does not provide very accurate results at low frequencies. It was observed that SM and G* value did not give correlated results until the frequency value reached the range of 10^{-5}-10^{-6} Hz. The same situation is also present at high frequency values. At this point, CA and CAM Models give more correlated results with G* values at very low and very high frequencies.
- The Huet-Sayegh Model is a mechanistic model and thanks to its physical elements, it reflects the effect of polymer modification rheologically more efficiently. At this point, it is more preferable for viscoelastic materials compared to CA and CAM models. Future studies aim to investigate the relationship between various mechanistic models and the behavior of polymer modified bitumen.

Consequently, using face masks, which has increased considerably in recent years, creates environmental problems. With the use of waste masks in asphalt modification, both the properties of asphalt have been improved, and waste management has been achieved by evaluating an environmentally harmful waste material. It is aimed to evaluate the performance of the WFM modified mixture in future studies.

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