Enhancing Skid Resistance of Two-Component Road Marking Paint using Mineral and Recycled Materials

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Abstract

Low skid resistance of road marking paint is one of the major issues in the safety of vehicle drivers, cyclists, and pedestrians when traveling on the city streets. Among the variety of marking paint, two-component paint is widely used at intersections and roundabouts. Therefore, the paint used should have adequate skid resistance. The object of this study was to evaluate the skid resistance and other physical properties of two-component road marking paint that is widely used in Tehran. Several additives were used and with the use of a British Pendulum Skid Resistance Tester, the skid resistance values (SRV) of the specimens were determined. In addition, abrasion resistance, reflectivity and adhesive properties of the specimens were evaluated. The tests results showed that the conventional road marking paint has a poor skid resistance. The problem may be resolved by using additive materials such as waste glass powder, silica granules and Lika (i.e. expanded clay).

Results suggest that waste glass powder has shown a better performance than the other additives, as it enhances the skid resistance of the paint. According to the pendulum test values, the application of waste glass powder as much as 10% by weight of road marking paint may respectively increase the skid resistance and reflectivity up to 21 units (from 38 to 59) and 40 units (from 239 to 279) so that it does not impose much negative impact on the other properties of the paint. It was found that the additive materials caused a reduction in the abrasion resistance of the road marking paint.

Keywords: Two-component road marking paint, skid resistance, abrasion resistance, reflectivity, adhesive strength

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1. Introduction

Two-component paint is a liquid substance mainly composed of two components of resin and a hardening agent (curing agent). In accordance with standard EN 1871: 2000, they belong to the cool colors group due to their nature and implementation. Since their efficiency is high and their lifetime is long, they are mainly used for marking high traffic roads and streets. A lifetime of two-component paint is about 3 or 4 years on roads with a significant traffic [Carlos, 2004]. In Iran, these are mainly used in crosswalks.

Two-component resins used for road marking include epoxy, polyester, polyurea, and polyurethane. Pigments used in two-component road marking paint are dispersed in resin component and they are responsible for creating color consistency. In addition, fillers (i.e. inorganic neutral compounds such as calcium carbonate and silica) are used to reduce the price and to provide improved physical and mechanical properties of the paint as well. Two-component road marking paint is a 100% solid and doesn't require the use of a solvent [Mir abdeni, 2007].

Enhancing the skid resistance of two-component road marking paint may prevent road traffic accidents to some extent (especially at intersections and roundabouts). The low surface friction of road marking paint would cause many accidents including pedestrian/vehicle crashes due to the skidding vehicles in places such as pedestrian crossings where the pavement surface is covered with marking paint. Considering the problems mentioned above, it is essential to assess and improve the skid resistance of road marking paint.

. Numerous studies have been conducted on the skid resistance of road marking paint. [Ludwig et al. 1976], investigated the effect of glass beads on the skid resistance of the road marking paint. They have reported that the glass beads not only improve the skid resistance of the road marking paint but also increase the reflectivity of it. Richards et al. 1997, investigated the effect of glass beads sprinkled on the marking paint on its skid resistance. They have also reported the improved skid resistance value (SRV) of the paint (from 24 to 40). Thew et al. 1997, evaluated the effect of pre-mixed glass beads on SRV of the marking paint and came to the conclusion that it was improved by 4 units (from 9 to 13).

[Harlow et al. 2005], with the use of sharp-cornered granules such as quartz and silica ones, improved the SRV of the marking paint by 10 units. According to them, the only disadvantage of using such sharp-cornered beads is the reduction in the reflectivity of the marking paint. Most researchers, in the previous studies, have investigated the skid resistance rather than the effect of additives on other properties of the marking paint. To the best of our knowledge, there has been no research conducted on the effect of silica granules and waste glass powder on improving the skid resistance of the road marking paint.

As mentioned above, the objective of this study was to investigate the effect of various additives on the properties of road marking paint (i.e. skid resistance, abrasion resistance, adhesive strength, and reflectivity).

2. Aggregates

The aggregate used to prepare the asphalt slabs were prepared from an aggregate mine around Tehran. Sand equivalent test, sodium sulfate soundness test, Los Angeles abrasion test, aggregate fractured faces test, Flakiness and elongation test, and Atterberg limit test were conducted for quality control of coarse and fine aggregate. Table 1 and table 2 give an overview of the conducted tests results. Figure 1 gives a schematic representation of the soil grading curve used in this study.

Table 1. Aggregate specific gravity

Characteristic	Specific gravity (g/cm3)	Apparent Specific gravity (g/cm3)	Water absorption (%)
Aggregate retained on No. 8 sieve	2.468	2.628	1.2
Aggregate passing No. 8 sieve and retained on No. 200 sieve	2.477	2.650	2.6
Aggregate passing No. 200 sieve		2.620	

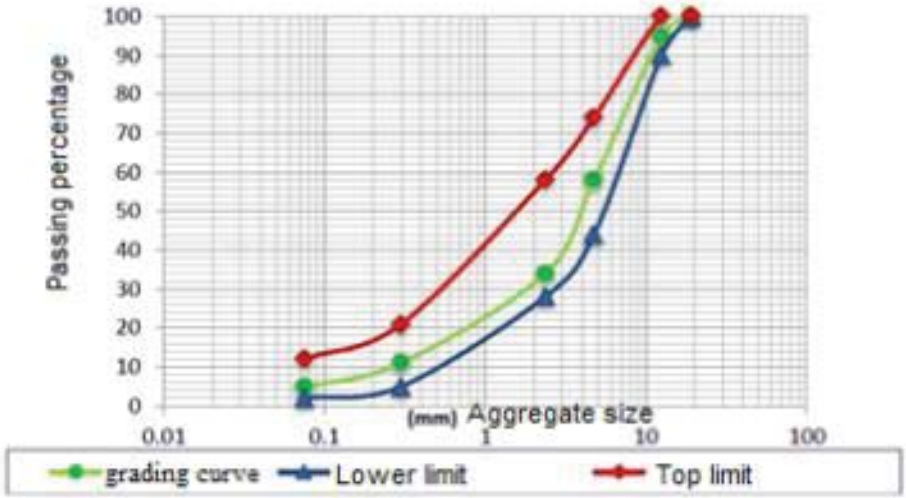

Figure 1. Soil grading curve

3. Two-Component Road Marking Paint

The marking paint used in this study was a two-component acrylic paint with the first component containing an acrylic resin (which has already been mixed with a catalyst) and the other compounds, and the second component containing peroxide. The paint drying time is 10-20 minutes in normal conditions and the dry film thickness is 400 microns to several millimeters [Hajmohamadi and Mohajerani, 2006].

4. Additives

Since the previous studies have used large amounts of round glass beads which affect other properties of the road marking material, in this study, the sharp-cornered silica granules, waste glass powders and Lika were used to reduce the amount of required additive and to improve the skid resistance of road marking paint. Maximum particle size was chosen 75% of the thickness of the marking paint. Four different particle gradations were chosen for the waste glass powder based on the paint thickness given in table 3. The additives used before and after grading are illustrated in figure 2.

5. Tests

After preparing the asphalt specimens, two-component marking paint was applied with a thickness of 800 microns. A laboratory-scale tool was used in order to apply the paint with the same thickness on the specimens. After selecting the desired thickness to be applied on, the tool was placed on the specimen's surface and the required amount of paint was uniformly poured on the surface, then using the tool which moved with a constant velocity, the entire surface was equally covered with the paint. The specimens were kept at 25 °C for 72 hours under laboratory conditions until the paint was completely dry afterward. The tests conducted on the samples are as follows:

Table 2. Aggregate characteristics

Coarse aggregate characteristics				
Test	Standard	Range		**Result**
		Minimum (%)	Maximum (%)	
Los Angeles abrasion	ASTM C131	-	۲۵	۲۹
Sodium sulfate soundness	ASTM C88	-	۸	**0.62**
Aggregate fractured faces	ASTM D 5821	۶۰	-	۹۱
Flakiness and elongation	ASTM D4791	-	۱۵	۲۵
Fine aggregate characteristics				
Plasticity Index (PI)	ASTM D4318	NP	NP	**NP**
Sodium sulfate soundness	ASTM C88	-	۱۲	**1.17**
Sand equivalent	ASTM D2419	۵۰	-	۶۹

Table 3. Waste glass powder gradation

Particle gradation No.	Waste glass powder particle size			
	75% of the thickness of the paint	50% of the thickness of the paint	25% of the thickness of the paint	**Less than 25% of the thickness of the paint**
1	100	۰	۰	۰
۲	۵۰	۵۰	۰	۰
۳	۲۵	۲۵	۲۵	۲۵

Figure 2. Additive materials before and after being grounded into powder

5.1 Skid Resistance

The skid resistance of the specimens was measured pursuant to ASTM E 303: 2007 standard taking advantage of a British Pendulum Tester. A rubber slider with the dimensions 75.75mm*25.4mm*6.35mm and the length of its path on the test surface equal to 12.5 mm was used. The test surface and the rubber slider must be completely clean and wet before testing.

5.2 Resistance to Abrasion

The resistance of the Topeka layer covered with the marking paint to abrasion was measured taking advantage of a Wet Track Abrasion Tester (WTAT). The test was performed in accordance with ASTM D3910:2005 standard. At first, the specimens were submerged in a water bath for 60 to 75 minutes at 25 °C. Then, the specimens were removed from the water bath and placed in WTAT machine (see figure 3). The specimens were removed from the chamber and after cleaning their surfaces, their resistance to abrasion was assessed in accordance with AS/NZS 4049:2007 standard afterward. The amount of remaining paint on the pavement surface is determined by comparing the images taken from the specimen's surface with the reference images based on the standard (Figure 4). In order to capture images, the specimens' surfaces were washed and then using a soft brush, they were cleaned and dried.

Figure. 3. WTAT machine

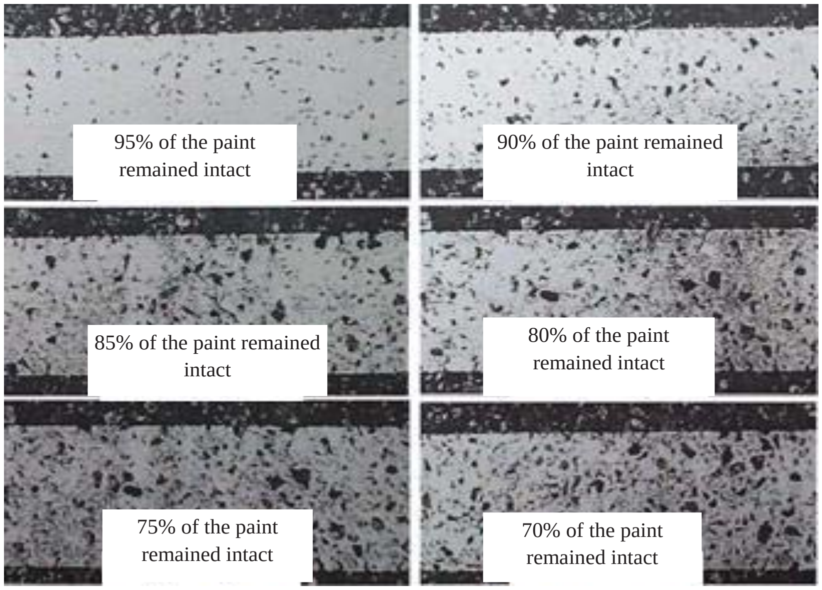

Figure 4. The AS/NZS 4049 standard reference images

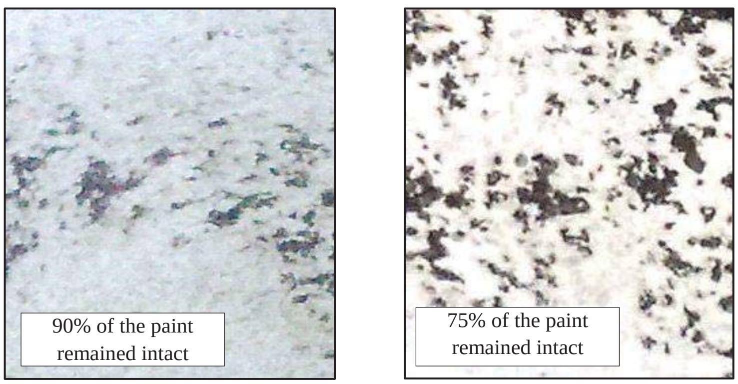

Figure 5. The images captured from the laboratory specimens

5.3 Reflectivity

The reflectivity of the specimens covered with the paint was measured taking advantage of a reflected light meter in accordance with the EN 1436:2003 standard. After 72 hours of applying the paint, the specimens with dimensions 10 cm * 50 cm are placed in the machine shown in Figure 6 to measure their reflectivity.

Figure 6. The specimens b) Reflected light meter

5.4 Pull off Test for Adhesion

The purpose of this test is to measure the mechanical tensile strength of a coating and it is conducted in accordance with the standard ACI 503:2003. In order to perform the test, After 72 hours of applying the paint on the specimen, its surface is cleaned by a special pad, then a circular steel disc is glued to the surface and after 24 hours, taking advantage of a scratching tool, the coating and adhesive is cut down to the substrate. The specimen is subjected to increasing tensile stresses until the weakest path through the material fractures afterward (figure 7).

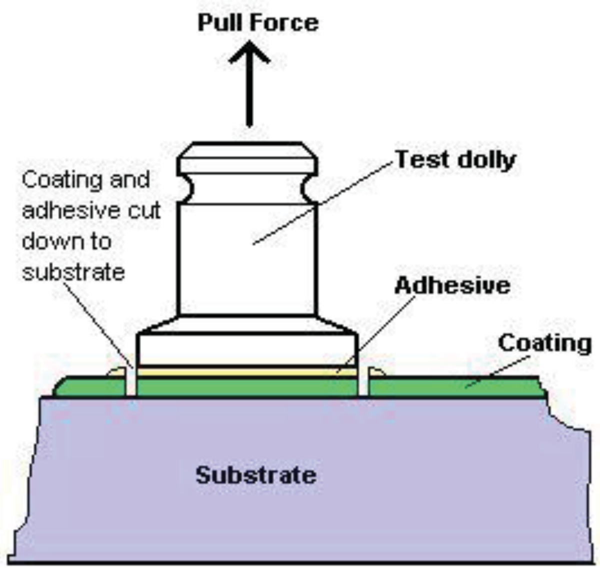

Figure 7. Pull off test for adhesion

6. Results and Discussion

6.1 The Effect of Various Additive Materials on the Properties of Road Marking Paint

In order to investigate the effect of additive materials such as waste glass powder, silica granules and Lika (i.e. expanded clay), the gradation No. 3 shown in table 3 was used. In order to perform the tests, 5 wt% of each additive material was mixed with the marking paint and it was applied on the specimens afterward.

6.1.1 Skid Resistance Test

The skid resistance of the specimens was measured taking advantage of a British Pendulum Tester. The resulted Skid Resistance Values (SRV) are illustrated in figure 8.

According to the figure, the skid resistance values of the specimens covered with the paint containing waste glass powder, silica granules, and Lika are increased up to 46%, 33%, and 26%, respectively.

6.1.2 Abrasion Test

The specimens were subjected to abrasion for 5 minutes. Since the additives were added to the liquid part of the paint, it didn't have a good adhesion to the additives and during the test, it was observed that the materials added to the paint were separated and resulted in a reduction in the abrasion resistance. In order to resolve the problem, the additives were added after mixing the hardening component with the liquid part of the paint. Table 4 gives an overview of the results obtained from the abrasion test.

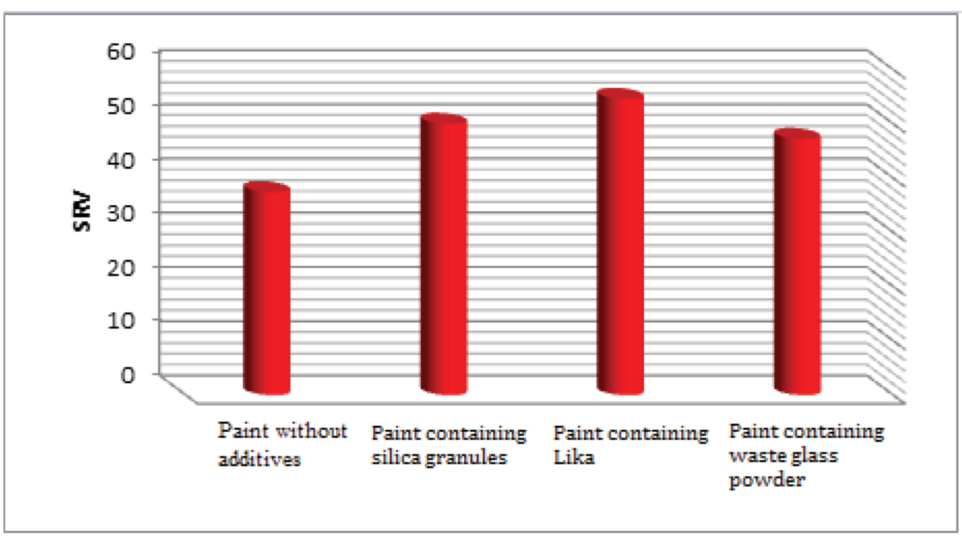

Figure 8. The skid resistance values of paint containing 5 wt.% of the additives

In order to evaluate the results listed in Table 4, a four-step variance analysis should be performed as follows:
Step one: hypotheses
The averages are not equal: H_1
the averages are equal: H_0
The statistics relating to the analysis of variances for the marking paint containing various additives are shown in Tables 5 to 7.

Table 4. Resistance to abrasion for the marking paint containing various additives
(the amount of paint remained on the surface (%))

Additives	Specimen No.			Average
	١	٢	٣	(%)
Paint without additives	95	90	90	**92**
Paint containing silica granules	80	80	75	**78**
Paint containing Lika	70	65	70	**68**
Paint containing waste glass powder	85	85	80	**84**

Table 5. The statistic relating to the analysis of variance for the paint containing silica granules

Sources of variation	Sum of squares	Degrees of freedom	Mean squares	F
Treatments	266.67	1	266.67	32
Errors	33.33	4	8.33	

Table 6. The statistic relating to the analysis of variance for the paint containing Lika

Sources of variation	Sum of squares	Degrees of freedom	Mean squares	F
Treatments	816.66	1	816.66	98
Errors	33.33	4	8.33	

Table 7. The statistic relating to the analysis of variance for the paint containing waste glass powder

Sources of variation	Sum of squares	Degrees of freedom	Mean squares	F
Treatments	104.17	1	104.17	12.50
Errors	33.33	4	8.33	

Step 3: critical value
In order to calculate the critical value, a 99% confidence interval is considered. The critical value is calculated taking advantage of equation 1.

$$F_{.01,1,4}=21.20 \quad (1)$$

Based on Tables 5 and 6, F=32 (for silica granules) and F=98 (for Lika) are more than the critical value for the significance level of 0.01. Therefore, the alternate hypothesis H1 is not rejected. Although silica granules and Lika (5% by weight of the marking paint) improve the skid resistance up to 35%, the abrasion resistance is reduced by 15% and 26% in their presence, respectively. As a result, they are not good choices to improve the skid resistance of the road marking paint. According to Table 7, F=12.5 (for waste glass powder) is less than the critical value for the significance level of 0.01. Therefore, the null hypothesis H0 is not rejected. Waste glass powder (5% by weight of paint) not only improves the skid resistance up to 35% but also doesn't impose a negative effect on the abrasion resistance of the marking paint. Consequently, it is a suitable additive for improving the skid resistance of the road marking paint.

3.1.6 Reflectivity Test

The reflectivity of the specimens covered with the paint containing the additive materials was measured using a reflected light meter. Figure 9 gives a schematic representation of the achieved results.

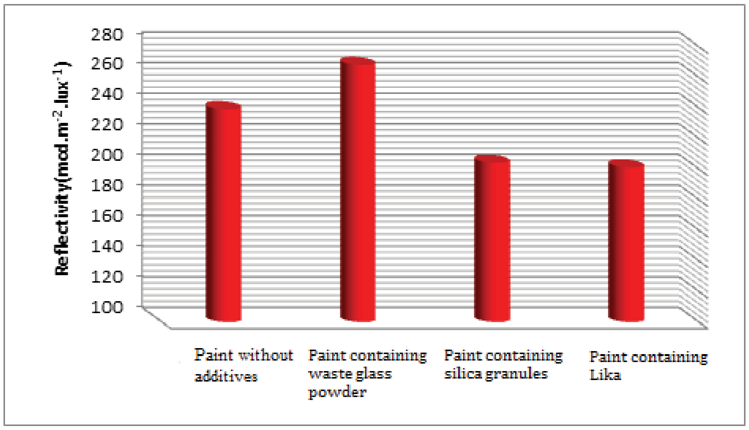

Fig. 9. Reflectivity of the paint containing various additives

It is evident from the figure that the silica granules and Lika (5% by weight of the marking paint) have reduced the reflectivity of the marking paint up to 15% while waste glass powder have improved the reflectivity of it up to 12%.

According to table 4 and figures 8 and 9, it is evident that silica granules and Lika have reduced the resistance to abrasion and the reflectivity of the marking paint, therefore, they are not a good choice for improving the skid resistance of the paint. Waste glass powder not only enhances the skid resistance of the paint but also improves the reflectivity of it.

6.2 Road Marking Paint Containing Waste Glass Powder with Different Particle Gradations

As was stated above, waste glass powder improved the performance in terms of skid resistance. Therefore, a further investigation was conducted on waste glass powder with different particle gradations. The specimens were prepared considering the particle gradations and dimensions given in table 3. The results obtained from the tests conducted on the specimens covered with the paint containing 10 wt% waste glass powder are as follows:

6.2.1 Abrasion Test

The abrasion test was conducted on the specimens covered with the marking paint containing 10 wt% waste glass powder and the results obtained are listed in table 8.

Based on Tables 8, F=32 (for particle gradation No. 1) and F=49 (for particle gradation No. 2) are more than the critical value for the significance level of 0.01. Therefore, the alternate hypothesis H1 is not rejected. Consequently, particle gradations No. 1 and No. 2 are not desirable choices for improving the abrasion resistance of the marking paint. F=12.5 (for waste glass powder) is less than the critical value for the significance level of 0.01 as well. Therefore, the null hypothesis H0 is not rejected. Accordingly, the particle gradation No. 3 is chosen to control the abrasion resistance of the marking paint.

Since the gradation No. 3 imposes a less negative impact on the abrasion resistance of the marking paint, it can be used to improve its skid resistance as well. After determining the best particle gradation, the optimum amount of the waste glass powder should be assessed. The specimens covered with the paint containing 5 wt%, 10 wt%, and 20 wt% waste glass powder were prepared for this purpose. The abrasion test was conducted on the specimens and the results are listed in table 9.

Table 8. The results obtained from the abrasion test conducted on the specimens covered with the paint containing 10wt% waste glass powder (the amount of paint remained intact on the surface (%))

	Specimen No.			Average
Particle gradation No.	1	2	3	(%)
Paint without additives	95	90	90	**92**
Paint containing waste glass powder with particle gradation No. 1	80	75	80	**80**
Paint containing waste glass powder with particle gradation No. 2	80	80	80	**82**
Paint containing waste glass powder with particle gradation No. 3	85	85	80	**84**

Table 9. Results obtained from the abrasion test conducted on the specimens covered with the paint containing different percentages of waste glass powder with particle gradation No. 3
(the amount of paint remained intact on the surface (%))

Wt% Additive	Specimen No.			Average
	1	2	3	(%)
Paint without additives	90	90	95	93
Paint containing 5 wt.% waste glass powder	85	90	90	88
Paint containing 10 wt.% waste glass powder	80	85	85	84
Paint containing 20 wt.% waste glass powder	80	75	80	78

According to tables 9, F=104.20 (for 20 wt% waste glass powder) is more than the critical value for the significance level of 0.01. Therefore, the alternate hypothesis H1 is not rejected. Consequently, adding 20 wt.% waste glass powder cannot control the abrasion resistance of the marking paint. F=12.71 (for 10 wt.% waste glass powder) and F=8.37 (for 5 wt.% waste glass powder) are more than the critical value for the significance level of 0.01. Therefore, the null hypothesis H0 is not rejected. It could be concluded that the marking paint containing 5 wt% and 10 wt.% waste glass powder reduces the abrasion resistance up to 5% while the marking paint containing 20 wt.% waste glass powder reduces the abrasion resistance up to 13%. As a result, 5 wt.% and 10 wt.% waste glass powder have shown a better performance.

6.2.2 Reflectivity

Figure 10 gives a schematic representation of the reflectivity of the marking paint containing waste glass powder.

According to figure 10, adding 5 wt. %, 10 wt. % and 20 wt. % waste glass powder have improved the reflectivity up to 14%, 17%, and 19%, respectively.

6.2.3 Adhesion Test

If the pull-off test is conducted on the marking paint applied on the asphalt surface, the aggregate on the surface will be separated. Therefore, it is not possible to comment on the adhesion of paint to the asphalt surface. In order to achieve accurate results, the marking paint containing waste glass powder was applied on a smooth stone and the pull-off test was conducted on the specimens. The results are illustrated in figure 11.

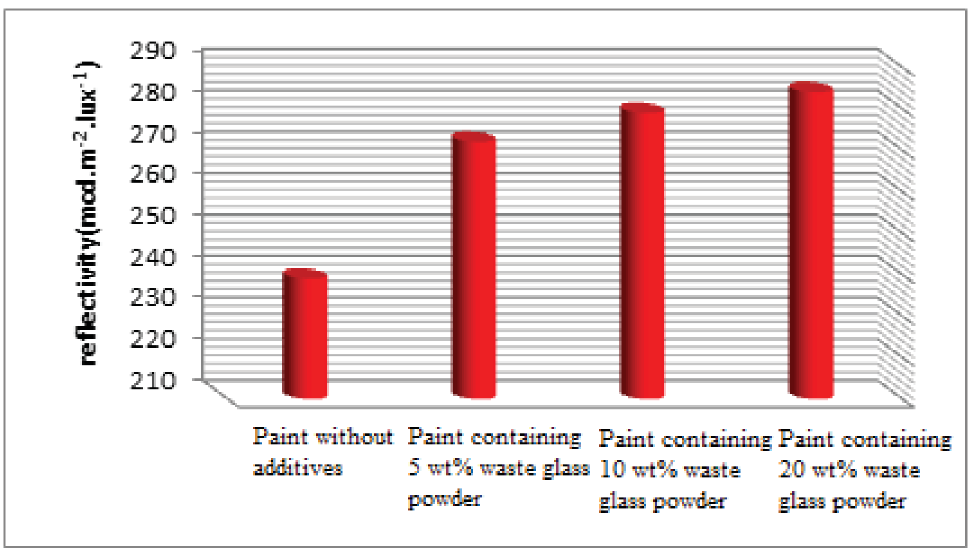

Figure 10. Reflectivity of the marking paint containing different percentages of waste glass powder

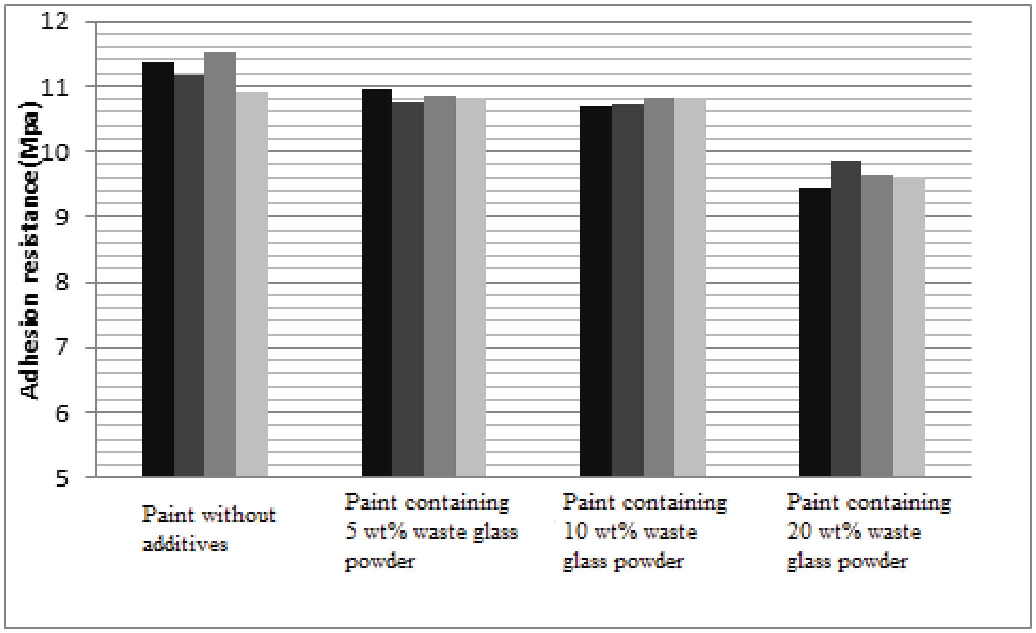

Figure 11. Adhesion resistance of the marking paint containing different percentages of waste glass powder

According to figure 11, adding 5 wt. %, 10 wt. % and 20 wt. % waste glass powder have reduced the adhesion resistance up to 3.5%, 4.3%, and 14%, respectively. As a result, 5 wt.% and 10 wt.% waste glass powder have shown a better performance in comparison with the larger amounts due to their less observed negative impact on the adhesion resistance of the marking paint.

6.2.4 Skid Resistance

Skid resistance of the specimens covered with the marking paint containing different percentages of the waste glass powder was measured. The results are schematically depicted in figure 12.

It is evident from figure 12 that the larger the amount of the waste glass powder is, the higher the skid resistance of the marking paint is. It can also be concluded that adding 5 wt.% and 10 wt% waste glass powder with particle gradation No. 3 have increased the skid resistance of the marking paint 39% and 58%, respectively. Since adding 10 wt.% waste glass powder have indicated a better performance than that of 5 wt.% waste glass powder, it is suggested as the proper amount to be added to the marking paint.

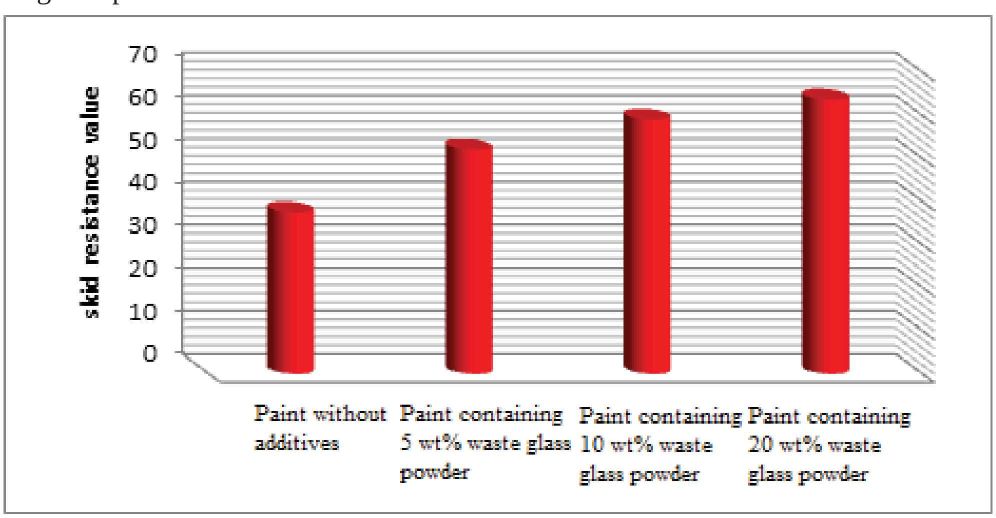

Figure 12. Skid resistance values of the paint containing different percentages of the waste glass powder

7. Conclusions

The following conclusions may be drawn from this study:

1. The addition of 5wt% silica granules, Lika and waste glass powder with particle gradation No.1 have improved the skid resistance of the road marking paint up to 13%, 10%, and 17%, respectively.
2. In order to improve the adhesion of the additive materials to the two-component marking paint, they should be added after mixing the two components of it.
3. Lika and silica granules (5% by weight of the marking paint) have not indicated a good performance in terms of abrasion resistance.
4. Although silica granules and Lika (5% by weight of the marking paint) improve the skid resistance, the abrasion resistance is reduced by 15% and 26% in their presence, respectively. Consequently, they are not a good choice to improve the skid resistance of the road marking paint.
5. Using waste glass powder with the particle gradation No. 3 have improved the skid resistance of the road marking paint and it doesn't impose any negative effects on its other properties.
6. In order to enhance the skid resistance of the two-component road marking paint, 10 wt% waste glass powder with the particle gradation No. 3 can be used. This can improve the skid resistance up to 58% (26 units).

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