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A Study on Surface Treatment for Rubber Materials with Low Friction Factor

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Abstract: Multi-Surface (MS) treatment is a new technique of surface treatment to reduce the static friction factor on the surface of rubber. MS treatments include 4 methods which names are MS-V (UV-irradiation on the rubber surface), MS-M (doing the chemical reaction with double bond of rubber), MS-Q (dilution of rubber surface by silicone surfactant), and MS-P (coating and heating of rubber surface). The experiment and test of every MS-treatment had been carried out using acrylonitrile-butadiene rubber (NBR), ethylene-propylene-diene rubber (EPDM), and chlorosulphonated rubber (CSM) as rubber materials. It had introduced the steps of every MS-treatment process and the result of the properties test. From the research, it was found that the best method was MS-V treatment because it suited all the samples and the effect was obviously.

Keywords: NBR, EPDM, CSM, surface treatment, friction factor

Introduction

Rubber is widely used in industry such as auto parts, electronic products, aerospace and other fields because it has great elasticity, medium resistance, abrasion resistance and electrical insulation.[1]

But mostly rubber is non-polar polymer, so there are so many researches to improve the properties of rubber, especially surface treatment to keep the original advantages inside and only change the properties of rubber surface such as moisture, weather resistance, permeability, adhesion, low friction, anti-static, adsorption, etc. The methods of surface treatment that are chemical modification and physical modification include: (1) add the polar groups on the surface; (2) decrease the interfacial energy; (3) decrease the roughness of surface; (4) eliminate the weak interface layer of surface.[2]

In this research, acrylonitrile-butadiene rubber (NBR), ethylene-propylene-diene rubber (EPDM), and chlorosulphonated rubber (CSM) are selected as rubber materials for a variety of tests(roughness, friction, hardness, density, rebound, abrasion resistance, and detach-ability).

MS-V means to use UV irradiation to evaporate the impurities of surface.[3] MS-M method is to make chemical reaction of double-combination between diene-rubber and a surfactant which has double bonds. MS-Q is to low the surface energy and tension of rubber.[4] MS-P means to make a coating layer on the surface of rubber. In this paper, we studied the best condition of MS treatment methods.[5]

Experimental

1. Materials

Acrylonitrile-butadiene rubber - 1052 J (AN 33.4%, Zeon, Japan), ethylene-propylene-diene rubber - EP 330 (ethylene 53.0~60.0%, Kumho) and chlorosulphonated polyethylene rubber - TS 530 (Cl 35%, Tosoh, Japan), surfactant SAT-615F (Shinko, Japan), oil emulsion silicone surfactant KMK-722 (ShinEtsu, Japan), silicone slip carrier emulsion HS-4 (Toshiba, Japan), phase transfer emulsion XC9603 (Momentive, USA), catalyst YC6831(Toshiba, USA) and toluene were used in this experiment.

2. Synthesis of Samples and Reagent

The test samples were produced by roll mill and heating press. Figure 1 shows types of samples for MS treatments. The agents were made by the methods below.

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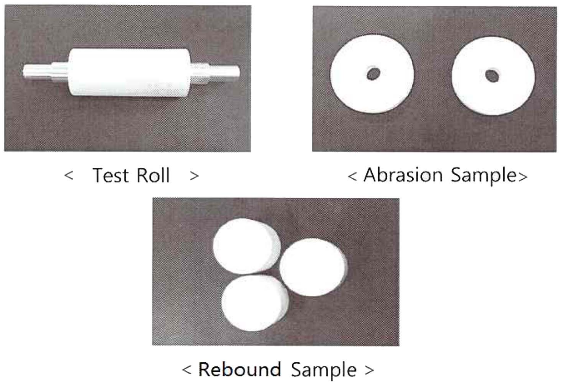


Figure 1. The experiment sample of MS treatment.

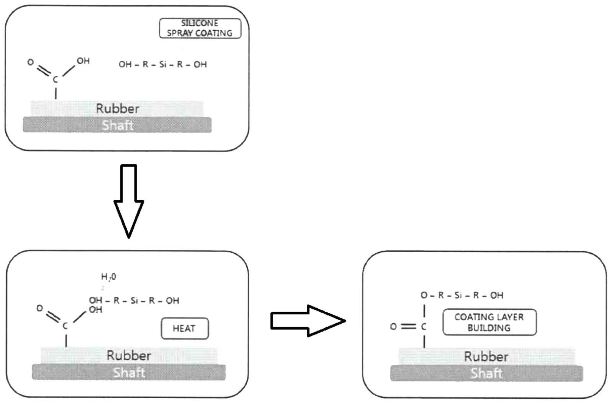


Figure 3. The principle of MS-P treatment.

MS-Q: dilute the oil emulsion silicone surfactant KMK-722 by water and then daub the emulsion on the sample surface to reduce the friction factor with the ratio of 7:3.

MS-P: mix up the silicone slip carrier emulsion HS-4 and phase transfer emulsion XC9603 and catalyst YC6831 and toluene[7] to make the coating on the surface and heating to get an esterification reaction which can make the surface smooth and reduce the friction factor with the ratio of 1:0.5:0.1:3.

MS-M: daub surfactant SAT-615F without dilution on the surface of rubber to make the chemical reaction of double combination of unsaturated vulcanization rubber.[6] It becomes possible to significantly raise the non-adhesiveness of rubber surface, low friction and adhesive property of rubber.

MS-V: only use anhydrous ethanol to clean the surface of rubber samples.

3. MS Treatment

MS-Q treatment: daub the agents with the different ratio and make the coating on the surface of sample at first, then put them into aging oven for 2 hours at least. Figure 2 shows the principle of MS-Q treatment.

MS-P treatment: make a coating of silicone surfactant and get an esterification reaction between the functional groups of rubber and silicone surfactant by heating, and reducing the friction factor by the coating layer building. Figure 3 shows the principle of MS-P treatment.

MS-M treatment: daub the surfactant SAT-615F without dilution onto the surface of rubber and then age the sample at the different heating temperature of 100 °C for the different aging time of 4 hours. Figure 4 shows the principle of MS-M treatment.

MS-V treatment: put the sample behind the U.V. lamp and control the time of 15 min and distance between light and samples with 10 cm. Figure 5 shows the principle of MS-V treatment.

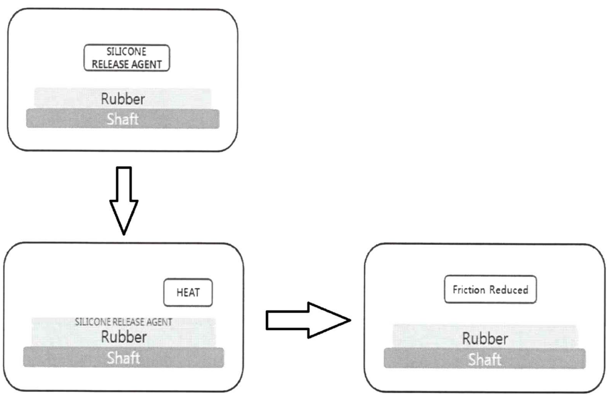


Figure 2. The principle of MS-Q treatment.

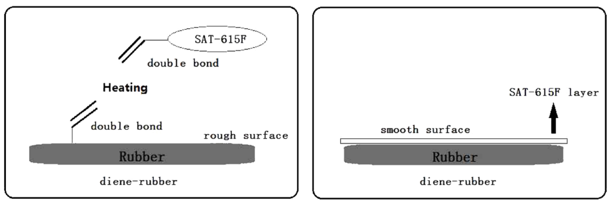


Figure 4. The principle of MS-M treatment.

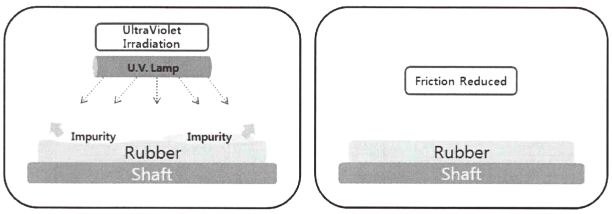


Figure 5. The principle of MS-V treatment.

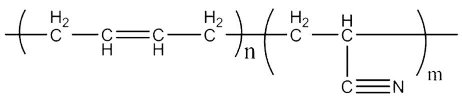
4. Characterization

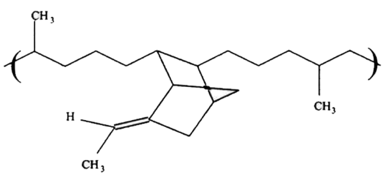
1. Roughness test : roughness test was performed at 25 °C before and after MS treatment by the Roughness test machine (Mitutoyo SJ-301).
2. Friction factor test : friction factor test was performed at 25 °C by friction factor test machine (HEIDON TRIBO-GEAR 94 i-II) before and after MS treatment.
3. Hardness test : hardness test was performed at 25 °C by Shore Durometer Type A before and after MS treatment.
4. Density test : density was performed by the density test machine to test the density fluctuation of samples before and after MS treatment.
5. Rebound test : rebound properties of samples were performed by the rebound tester before and after MS treatment.
6. Abrasion resistance test : abrasion resistance properties were performed by using Abrasion resistance tester through 1000 cycles of abrasion to measure the difference of abrasion resistance properties before and after MS treatment.[8]
7. Detach-ability test : detach-ability was performed on 25 °C by the test machine (IMADA DS2-200N force measurement) to test the change of detach properties before and after MS treatment.

Results and Discussion

1. Roughness and friction properties after MS treatment

Roughness is usually measured as a sum of negative and positive deviations from a "mean plane" fit over the surface of interest. Friction factor reducing is the research goal. Figure 6 represents the chemical structures of the three rubbers


(1)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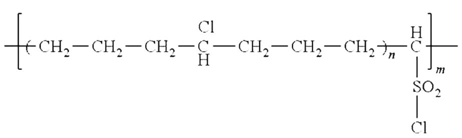
(3)

Figure 6. The structure of NBR rubber (1), EPDM rubber (2), CSM rubber (3).

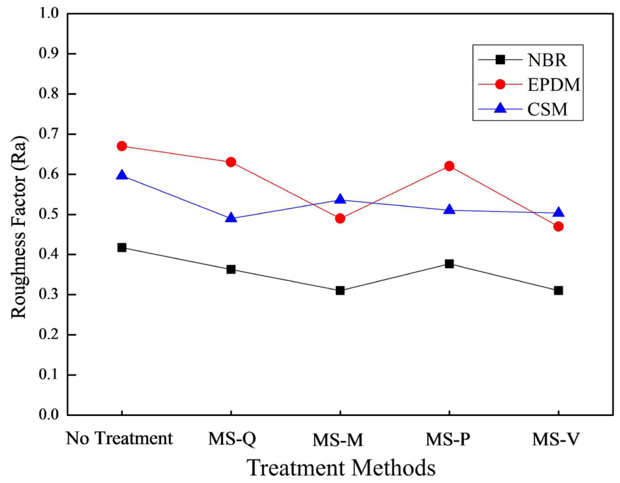

Figure 7. The curves of roughness factor with MS treatment.

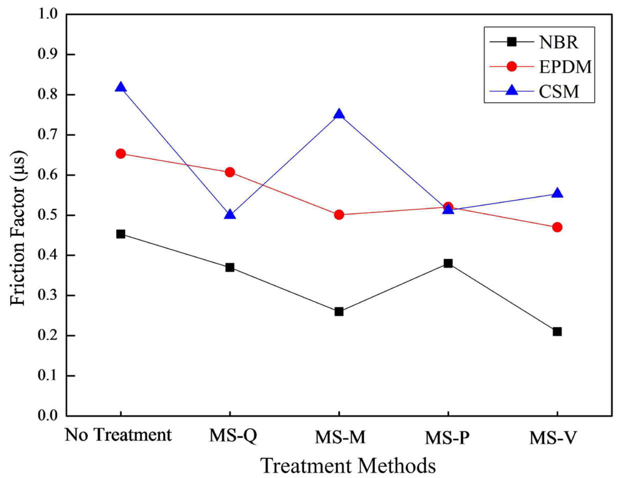

Figure 8. The curves of friction factor with MS treatment.

used in the research and test results were shown in Figure 7 and Figure 8.

From the Figure 7, the roughness of samples surface has been shown it had a trend of decreasing after every MS treatment. The roughness decreasing of EPDM's roughness factor is not so much especially in MS-Q and MS-P treatment. This is because both MS-Q and MS-P treatment used silicone as the agent of treatment, there isn't any acid group or other group to react chemically with silicone in EPDM rubber (the structure is shown in Figure 6). The silicone agent can't make a stable surface layer on the EPDM rubber,[9] thus the roughnesses of MS-Q and MS-P are larger than those of MS-M and MS-V.

As shown from Figure 8, the friction factor has been decreased obviously, and the curves of friction factor had the same trend with the roughness factor curves. The best material is NBR above all and the best method is MS-V treatment.

This means that with the irradiation of U.V. lamp, the impurity of rubber surface has been evaporated. This method suits all the sample so it is the best methods. For MS-M treatment and the agent SAT-615F which can fill the gaps of rubber surface only works on the diene-rubber such as NBR and EPDM (the structures are shown in Figure 6), the effect is based on the number of double bonds on the rubber surface. As there is the more double bonds in the rubber the structure of layer becomes the more stable and the friction factor is decreasing. For CSM rubber, however there isn't any double bond that MS-M treatment's effect for CSM rubber is not obviously. The effect of MS-Q and MS-P treatments is great because there are chlorosulfonic groups in the repeat unit of CSM rubber. It can be combined well with the hydroxyl groups which are in silicone agent to show good effect than MS-V treatment on the CSM rubber.

2. Hardness, density and rebound after MS treatment

The property of hardness has been shown in Figure 9. It can be found from the curves that the hardness properties of all samples after MS-M and MS-V treatment had improved. This is because in MS-M treatment, all the samples had reacted with agent SAT-615F which can make a layer on the sample surface. In MS-V treatment, after U.V. Lamp treatment, the water and impurity on the surface had been evaporated which has same effect as aging treatment. It can make the surface harder than before. In MS-Q and MS-P treatment, the silicone agent will make a coating of ester and other polymer on the surface of rubber which can make surface softer than before.

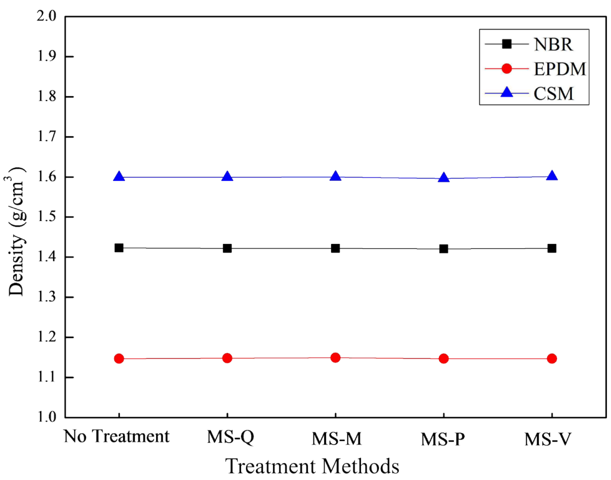

Figure 9. The curves of hardness with MS treatment.

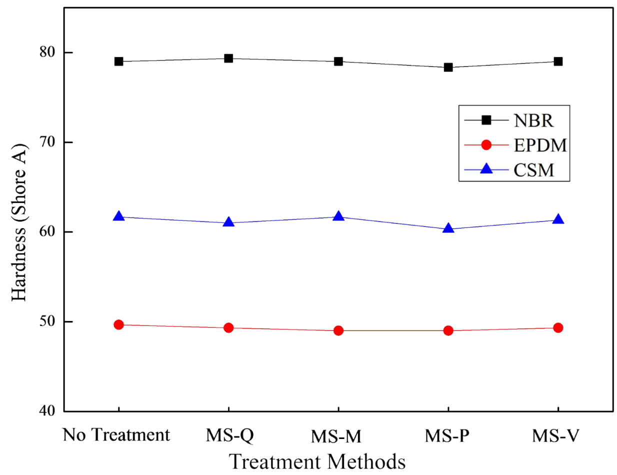

Figure 10. The curves of density with MS treatment.

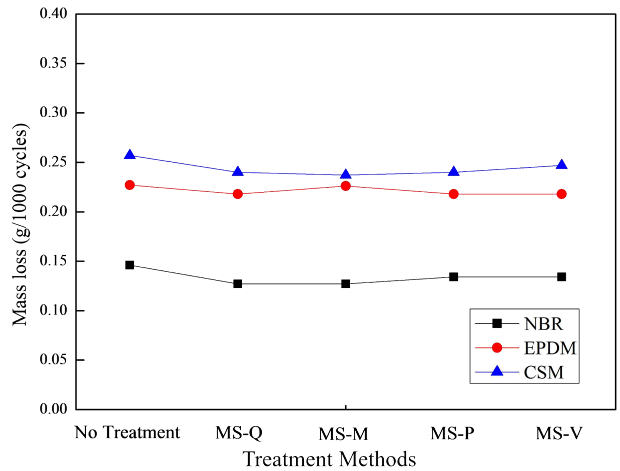

Figure 11. The curves of rebound with MS treatment.

The density change had been shown in the curves of Figure 10. The density didn't have obviously change before and after MS treatment. This is because MS treatment just treated the surface. It didn't matter with density property.

From Figure 11, the rebound properties have been tested as the curves show. In MS-M treatment, the data of CSM rubber and EPDM rubber had decreased obviously, this is because the coating of agent SAT-615F can make the surface harder than before which can decrease the rebound properties, but for NBR rubber, there were more double bonds on the surface which can combine this agent better than other rubbers, it can make the surface and agent more uniform as a whole, the rebound property had been also increased. For MS-P, the silicone spray coating reacts with the rubber in an esterification reaction which can make the sample softer than before (it's shown in Figure 9), in this way, the properties of rebound are also increasing with the hardness decreasing.

The results of these tests showed that the change of these properties was not obviously. It proved all the samples just kept these three properties inside as before the MS treatment.

3. Abrasion resistance and detach-ability after MS treatment

As an important property of application in producing process, the resistance of materials and structures to abrasion can be measured by the amount of mass loss per 1000 cycles of abrasion.

The results of abrasion resistance properties were shown in Figure 12. It can be found that the abrasion resistance properties of all the samples had been improved.

The abrasion resistance properties don't only rely on the roughness and friction factor, but also depend on hardness and density of rubber samples. The mass loss per 1000 cycles

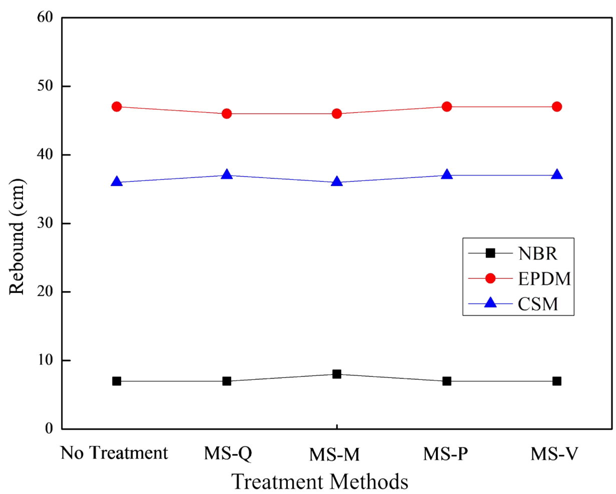

Figure 12. The curves of abrasion resistance with MS treatment.

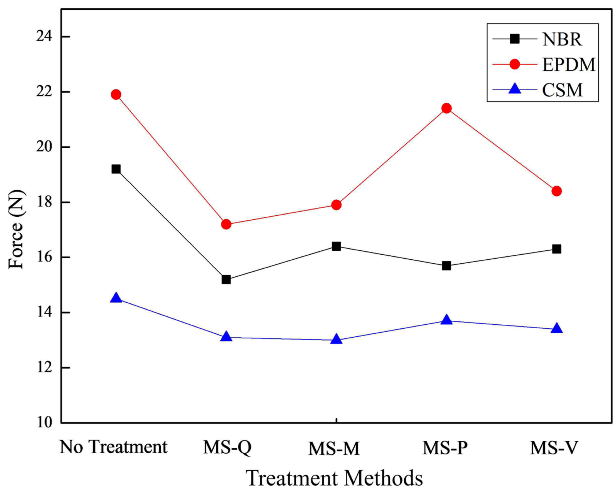

Figure 13. The curves of detach-ability with MS treatment.

had been reduced after MS treatment and the best method to reduce the mass loss is MS-Q treatment.

The result of detach-ability was shown in the curves of Figure 13. From these curves, the detach-ability had been improved after MS treatments. For EPDM rubber samples, the best two methods are MS-Q and MS-M. This is because the agent of MS-Q and MS-M covered the surface of rubber which decreased the surface tension and the detach-ability. But for MS-P, the agent also covered the surface of EPDM to introduce the hydroxyl groups from silicone agent which can increase the surface tension. The MS-P treatment didn't work for detach-ability property.

Conclusion

MS treatment was created as a new technique of surface treatment to reduce the static friction factor on the surface of rubber, especially in producing process. In this study, 4 kinds of methods are all proved they have effects in reducing friction factor of surface in the roughness test, friction factor test, abrasion resistance test and detach-ability test. It was also proved that the properties inside is not changed by the test of hardness, density and rebound property. The best method is MS-V treatment because it suits all the samples, but the other treatment methods also have advantages in the process of practical production. The MS treatment method shows a promising technique for further future application in rubber productions including rolls, seal, cable jacketing, and so on.

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