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Enhancing Safety and Slip Resistance of Epoxy Flooring Materials through the Reuse of Aluminum Machining Chips

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Abstract. The present study is part of a wide research project conducted by the authors. The overarching purpose of this project is to explore the reuse of aluminum machining chips for the development of design recommendations for epoxy floor materials, specifically focusing on safety requirements and slip resistance based on friction measurements. The aim is to address the potential danger of electrostatic charge generation during walking.

Epoxy floor coatings are commonly used in commercial and industrial settings. They are typically applied over concrete floors to create a smooth, durable surface that can withstand heavy loads and provide a high-performance flooring solution. Many industrial sites, warehouses, and commercial buildings rely on epoxy floors to maintain clean and safe conditions for workers, equipment, and inventory.

In this study, we propose the reuse of aluminum machining chips as filling material for epoxy flooring. The goal is to increase the friction coefficient and reduce the electrostatic charge generated by the friction between shoes and epoxy flooring materials.

The test results demonstrate that the safety of shoes increases with a decrease in the hardness of the shoe sole. Additionally, the friction coefficient increases with the increasing aluminum powder content in the epoxy flooring material. Based on these findings, we recommend the use of aluminum machining chips to improve the safety of epoxy flooring materials. The incorporation of aluminum powder in epoxy flooring helps water to escape from the contact surface during walking, thereby enhancing floor safety, especially in rainy weather conditions. We also advise the safe disposal of machining chips to produce new products.

Keywords. Safety, Epoxy, friction coefficient, electrostatic charge, Shore hardness, aluminum powder.

1 INTRODUCTION

The selection of materials with higher coefficient of friction leads in decreasing slip and fall accidents. In order to increase strength, it is common for floors in different workplaces to be made from hard and smooth materials. To achieve an increased comfortable in working areas, rubber mat has become common floor material, [1 – 7].

The usage of recycled rubber can be found in many workplaces as, in floors in health clubs, gyms, community centers, fitness centers, universities, fire, and police stations and play areas as well as schools. The effect of sand particles, on the friction coefficient done by rubber sliding versus ceramic tiles at various situation, was studied, [8].

Tests were carried out at water, dry, soap, detergent, oil, and water oil emulsion. It was noticed that, at dry sliding, dust particles caused excessive reduction in friction coefficient. In this state, it is recommended to utilize rounded protrusion in the rubber surface. In the presence of sand, dust particles instill in rubber surface this action related to increased friction coefficient. The results show, wet square protrusions are bespoken to have comparatively higher friction coefficient values. At surfaces lubricated by soap diluted by water, smooth rubber embedded by sand particles accord higher friction compared with protruded rubber surface; however, sand particles embedded in rubber surface lubricated by oil display higher coefficient of friction values. Many studies have been investigated for improving the tribological and triboelectrification properties of epoxy flooring materials, [9 -12].

It was observed that, from tests were carried out at water, dry, soap, detergent, oil, and water oil emulsion, at dry sliding, dust particles caused overreduction in friction coefficient. To took advantage of this situation, it is recommended to use rounded protrusion in the rubber surface. Smooth rubber embedded with sand particles gives higher friction compared to the protruded rubber surface when handling surfaces lubricated with soap diluted with water; Note that sand particles embedded in the oil-lubricated rubber surface display a higher coefficient of friction. Many studies have been investigated for improving the tribological and triboelectrification properties of epoxy flooring materials, [9 -12].

Coefficient of friction noticeably is increased as result of using rubber particles from experimental results. This attitude concerning to the deformation of rubber through scratching. The lowest value of coefficient of friction noticed for pure epoxy specimens was 1.5 at 4 N applied load, however the maximum value was 2.5 displayed by epoxy filing by 10 wt. % rubber of 0.5 – 1.0 mm particle size, [13]. The examined material is polyester filled by various contents of recycled rubber 5, 10, 15, 20 and 25 % with various particle sizes. Experiment shows that, increases rubber content shows important increasing in coefficient of friction for polyester composite. The maximum value of coefficient of friction was (1.75) for polyester composite spotted at polyester specimens contain 25 % rubber. However: the minimum friction value (0.18) noticed at 100% polyester specimens. Increasing particle size of rubber displays remarkable increase in wear of polyester composite, [14].

14.4% of all reportable work accidents in Germany in 2020 originated from Tripping, falling and slipping on floors [15]. Flooring in work areas must be designed in such a way as to avoid this, a reality enforced by law in many countries. In Austria and Germany, for example, this is specified in the relevant workplace regulations [16]. Slip resistance can be defined as property of the surface of a floor intended to stop the foot from slipping when a foot or shoe sole is covered with slip-enhancing substances such as water or oil. The biomechanical principles for slipping are described in Ref. [17], for example. The slip resistance is influenced by more than one factor, including human factors, but three dominate: the shoe sole, the floor covering material and the slip- promoting intermediate medium, such as spilled oil or water. If an intermediate medium is present, the influence of the floor covering and especially of the shoe is reduced. Further investigations can be found, for example, in Ref. [18], where various shoes and coatings were examined with regard to their slip resistance. It necessary also to mention that roughness parameters can be used for the evaluation of the slip resistance as described in Refs. [19 - 20], where [21] specifically deal with those in food industry buildings. The topic represents a subsection of the hygiene and health requirements in buildings.

Measurements of the static coefficient of friction between rubber specimens and ceramic surfaces were performed in dry, water lubricated, oil diluted by water, oil and sand that contaminates lubricating fluids [22-24]. It is recorded that; dry sliding of the rubber test samples revealed the higher value of coefficient of friction. In case of wet lubricated ceramics in comparison with dry sliding, the value of the friction coefficient is reduced. For oil lubricated ceramic, friction coefficient reduced with increasing length of the grooves comes in the rubber specimens. Besides, diluting oil by water showed values of friction coefficient much lower than that spotted for oil lubricated condition. As for ceramic covered by water and soap and impure by sand, coefficient of friction shows remarkable increases compared to the sliding case, of water and soap only. In the existence of oil and sand on the sliding surface, the friction coefficient lightly increased. This attitude may be occasion by sand embedment in rubber surface and consequently the contact became amidst sand and ceramic. At lubricated sliding surface by water and oil dirty by sand, the friction coefficient showed higher value than that of sand and oil sliding conditions.

The amount of industrial waste around the world is increased proportionally with continuing increase in production volumes, in recent years, the general trend is to reduce the amount of industrial waste by promoting the reuse of waste and the use of recyclable materials, as well as developing and improving manufacturing technology. [25]. In the last few years, non-conventional machining methods have greatly evolved in order to cut materials without generating chips or generating microscopic chips. In spite of the characteristics of non-conventional machining methods such as high precision, high surface finish, ability to produce complex shapes, and reduced waste due to low or no wear, non-conventional machining methods are not economical for low mass production due to the high cost and low demineralization rate [26]. Therefore, traditional manufacturing processes are needed by industrial market, which increases the waste volume, [27]. If waste materials are eliminated from a product's life cycle during manufacturing without being reused, they have a detrimental impact on the environment. Aside from contamination, a new product may be manufactured cost-effectively throughout a chain by reusing manufactured waste or worthless materials.

The present work aims to reuse the machining aluminum chip for improve the safety of epoxy as flooring materials in rainy weather.

2. EXPERIMENTAL WORK

The Ultra Stable Surface Voltmeter (USSV) was utilized to measure the electrostatic charge generated during contact and separation of the specimens against rubber, as shown in Figure 1. The USSV is capable of measuring charges as low as 1/10 volt on a surface and up to 20 kV. Readings in volts are typically taken with the sensor positioned 25 mm away from the surface being tested.

Fig. 1 Electric static charge (voltage) measuring device.

Friction tests were conducted using a specially designed and manufactured test rig to measure the friction coefficient between the rubber test specimens and the flooring tiles being tested. The test rig was equipped with sensors to measure both the frictional and normal forces involved in the testing process.

The tested flooring tiles were positioned on a base supported by two load cells. The first load cell measured the horizontal force (friction force), while the second load cell measured the vertical force (normal load). By calculating the ratio between the friction and normal forces, the friction coefficient was determined.

The setup and arrangement of the test rig are depicted in Figure 2.

Firstly, the machining aluminum chips were milled using a ball mill to obtain aluminum powder, as shown in Figure 3. Test specimens were then prepared by mixing the aluminum chip powder with epoxy resin and molding it onto a wooden block, forming a tile with dimensions of 150×150 mm^2. The preparation process of the test specimens is depicted in Figure 4.

For the experiments, aluminum chip powder with a particle size of 5 microns was added to the epoxy resin at different weight percentages: 1%, 2%, 3%, 4%, and 5%. Friction tests were conducted under various normal load conditions to cover both light and heavy loads.

To measure the sliding modes, rubber shoes with different hardness values of 63, 65, and 67 Shore "A" were used. The rubber shoes used in the experiments are shown in Figure 5. The Shore "A" Hardness meter used for measurement is depicted in Figure 6.

In order to evaluate the effect of water on the epoxy surface, 5 ml of water was applied. The presence of water on the epoxy surface filled with aluminum chip powder is illustrated in Figure 7.

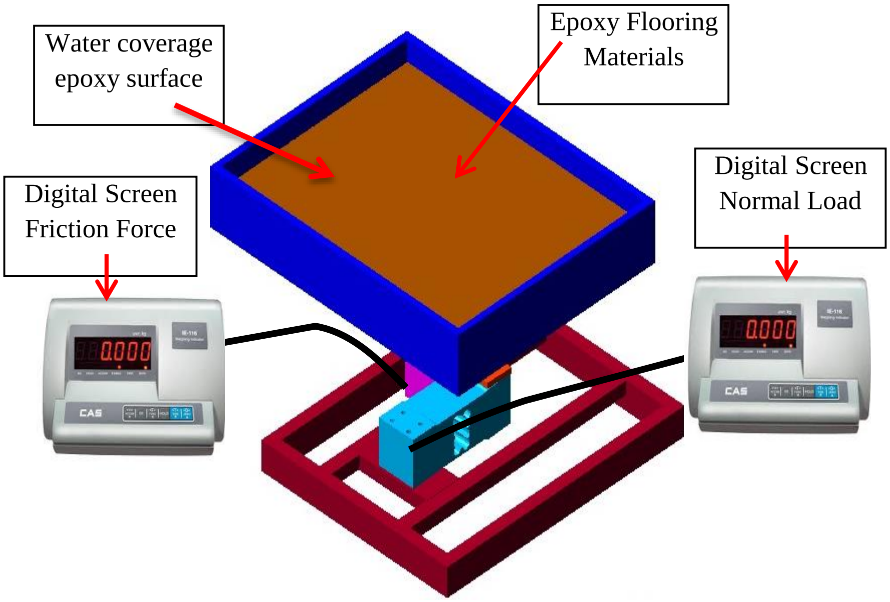


Fig. 2 Friction test rig

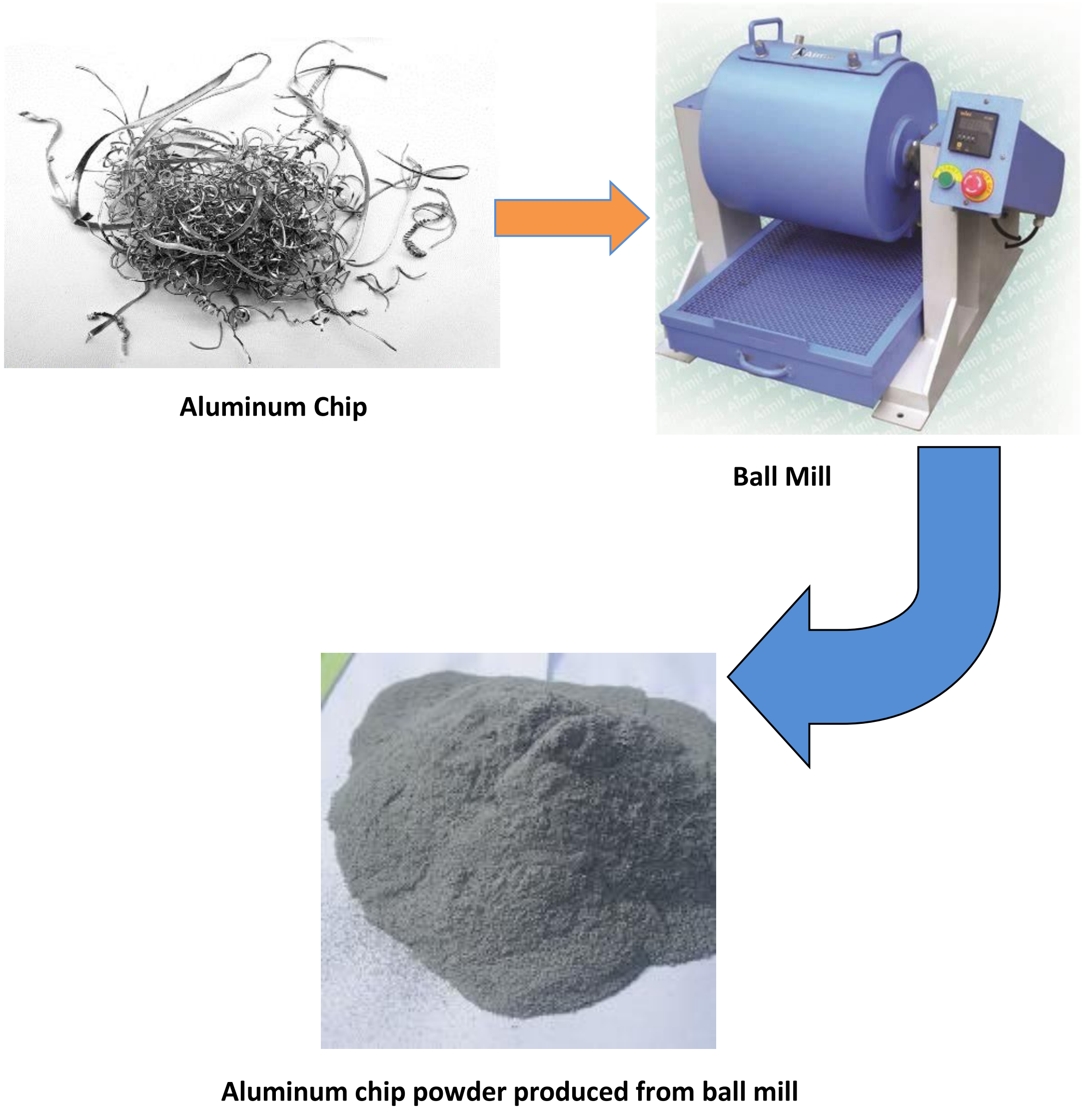
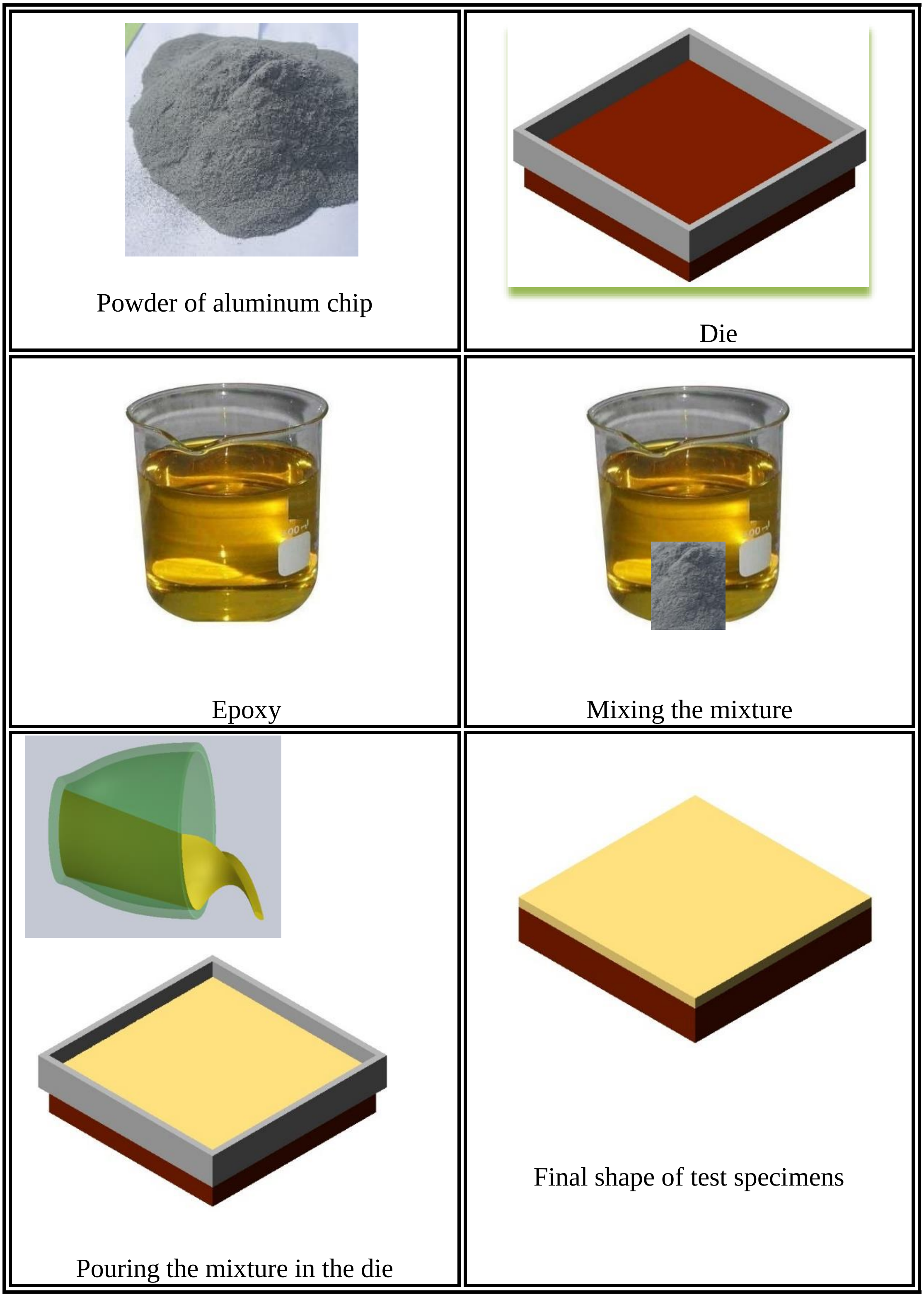


Fig. 3. Aluminum machining chip milling by Ball mill to produce the aluminum powder.



Powder of aluminum chip

Die

Epoxy

Mixing the mixture

Pouring the mixture in the die

Final shape of test specimens

Fig. 4 Epoxy test specimens filled by powder of aluminum chip.

Fig. 5. Tested rubber shoes.

Fig. 6. Shore "A" Hardness meter.

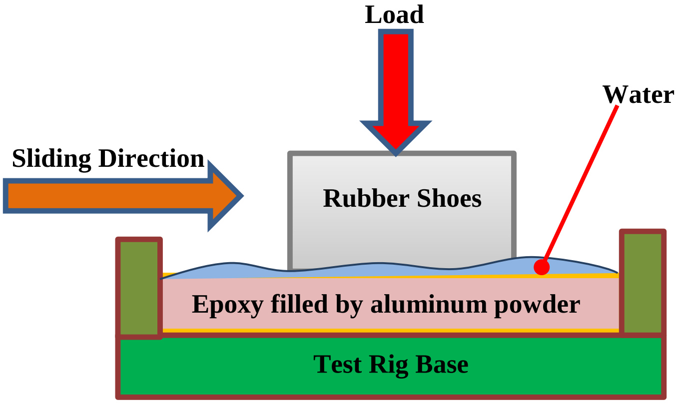


Fig.7 Illustration of the tested rubber shoes sliding against epoxy surface filled by copper powder in water sliding conditions.

4. RESULTS AND DISCUSSION

Friction coefficient of epoxy flooring material filled by powder of aluminum chip is shown in Fig. 8. Friction coefficient slightly increases with increasing Al. powder content. Increase hardness of shoes decrease the deformation, this behavior results reduction in friction coefficient. In presence of water on sliding surface easy to slip shoes on flooring surface. The minimum values of friction coefficient were observed for 100% epoxy specimens. Increasing aluminum powder content up to 2% show more effect in increasing friction coefficient.

Figure 9 show the relation between friction coefficient and normal load, for water sliding epoxy test specimens filled by powder of aluminum powder. It can be noticed that the friction coefficient decreases with increasing normal load. This behavior related to difficult to escape water from contact area. The friction coefficient increases with increasing aluminum powder content. The minimum values of friction coefficient displayed by pure epoxy test specimens.

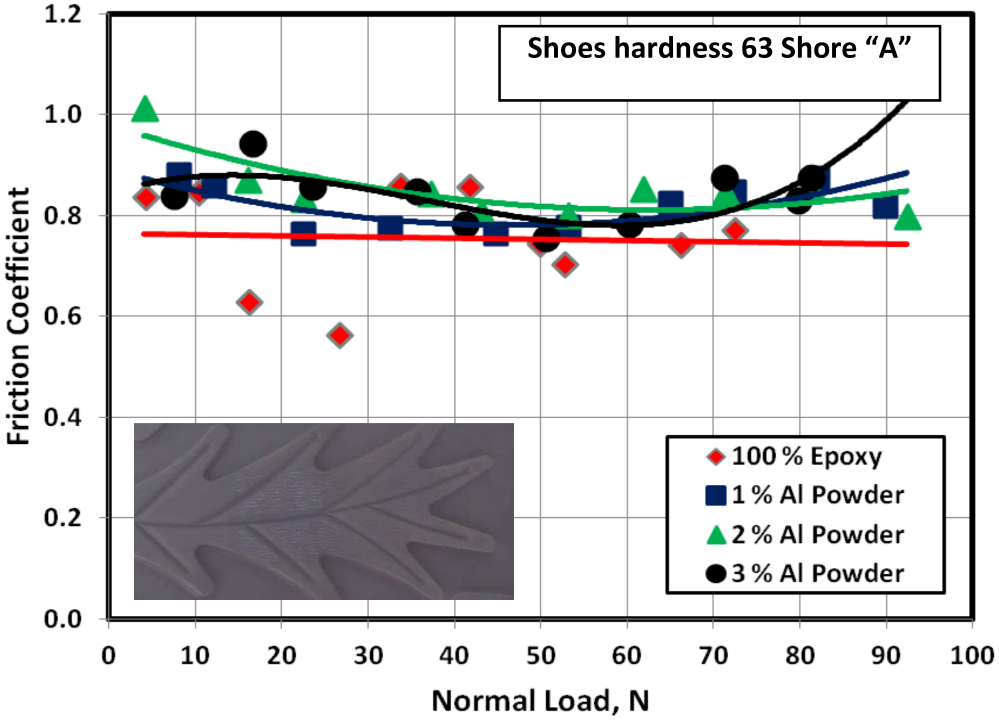


Fig. 8 Friction coefficient of rubber shoes with Hardness 63 shore A sliding against wet epoxy floor filled by aluminum powder.

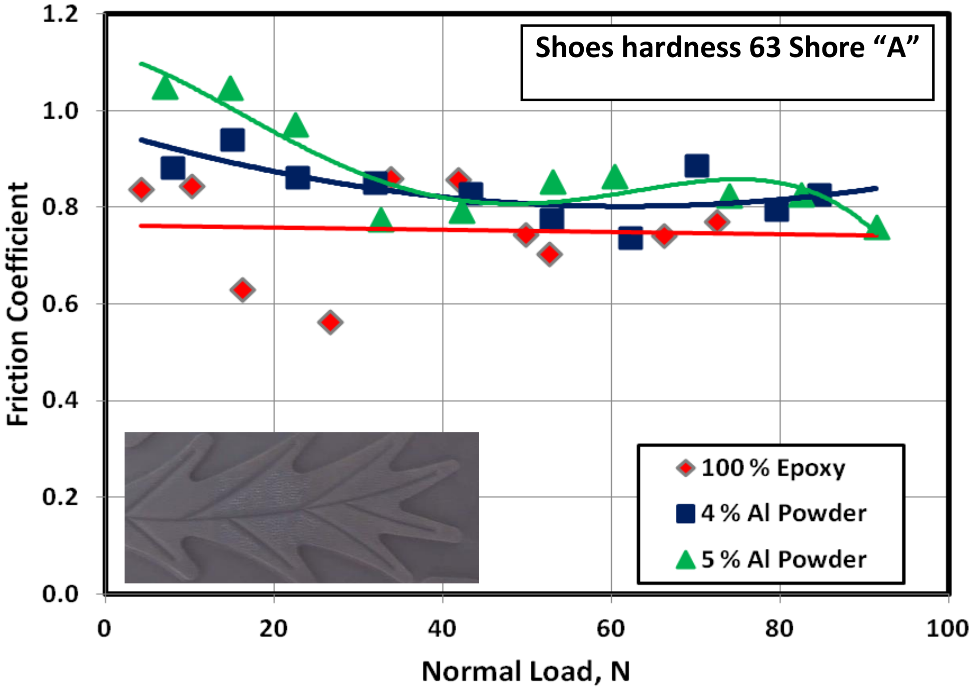


Fig. 9 Friction coefficient of rubber shoes with Hardness 63 shore A sliding against wet epoxy floor filled by aluminum powder.

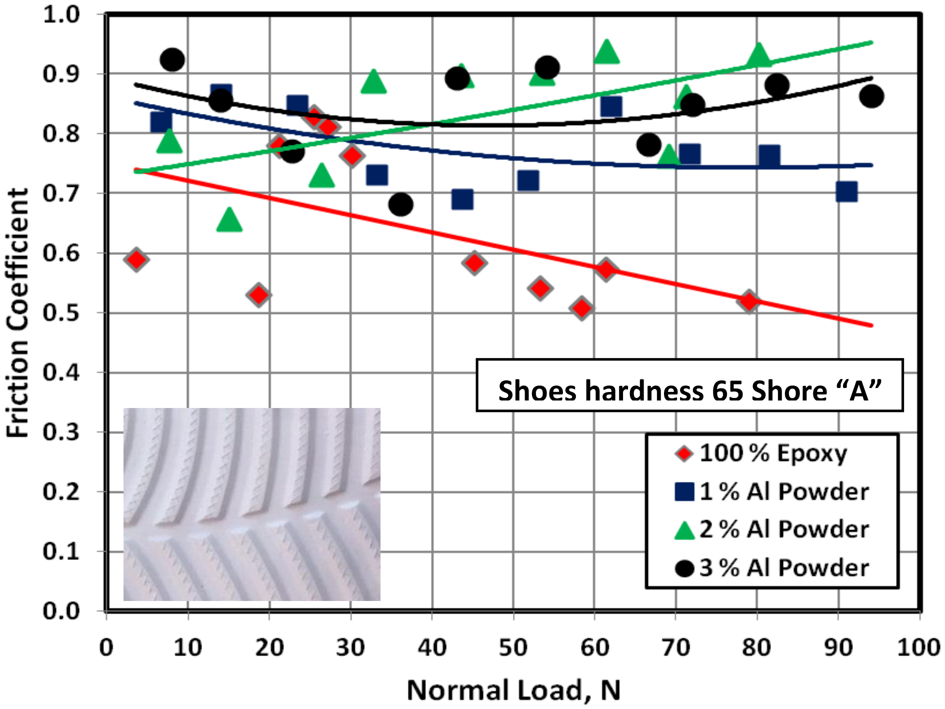


Fig. 10 Friction coefficient of rubber shoes with Hardness 65 shore A sliding against wet epoxy floor filled by aluminum powder.

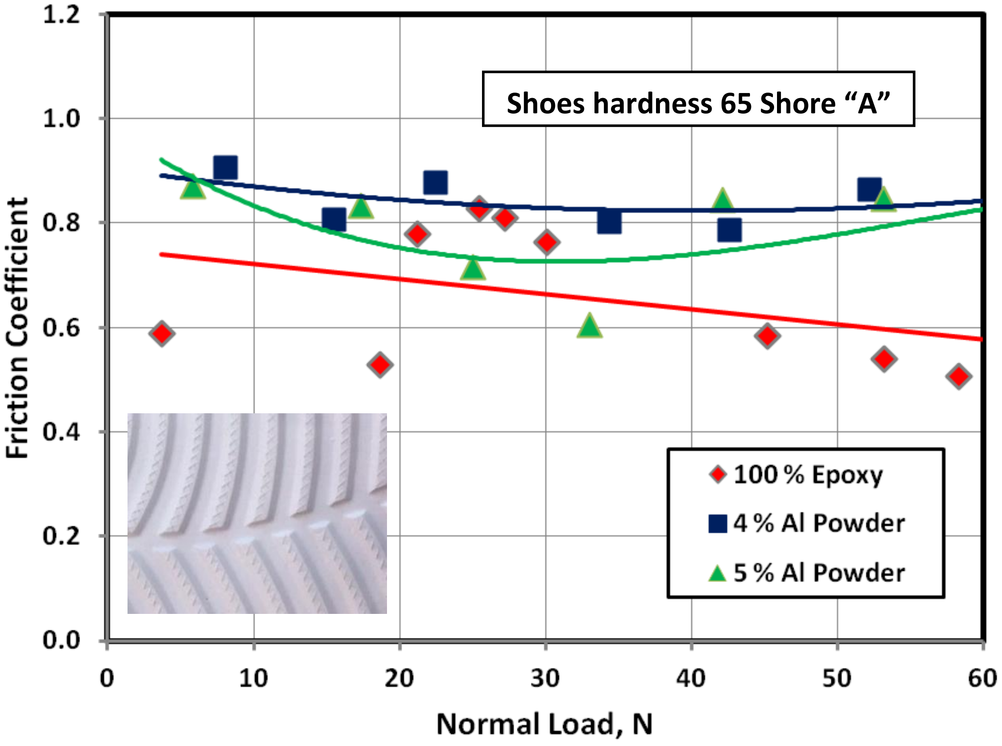


Fig. 11 Friction coefficient of rubber shoes with Hardness 65 shore A

Figure 10 shows the relation between friction coefficient and normal load, for water epoxy filled by powder of aluminum chip. It can be noticed that the friction coefficient increases with increasing Al. content. This behavior may be related to the aluminum powder help for leakage water from contact area. Aluminum powder show significant effect on increasing friction coefficient. Maximum friction coefficient was observed at 2 % aluminum powder.

Increase powder of aluminum chip content in epoxy flooring is shown in Fig. 11. Friction coefficient shows slightly increase with increasing aluminum powder content. Friction coefficient slightly decreased with increasing normal load. This behavior related to retention the water in contact area. Minimum values of friction coefficient were observed for 100% epoxy flooring. Adding aluminum powder by 4 % show significant effect on increasing friction coefficient.

Friction coefficient of rubber shoes sliding against epoxy test specimens filled by powder of aluminum chip is shown in Fig. 12. Friction coefficient increase with increasing powder of aluminum chip content. This behavior may be related to increase resistance of flooring for sliding. Decrease hardness of shoes play important role in increasing deformation of shoes sole that help water to escape from contact area. The maximum value of friction coefficient was observed at specimens of epoxy filled by 3% powder of steel chip. The minimum value of friction coefficient was observed at 100% epoxy flooring material.

Figure 13 show the relation between friction coefficient and normal load, for epoxy test specimens at 4% and 5% Al. powder content. It can be noticed that the friction coefficient increased with increasing Al. powder content. Increase Al. powder content to 5% show enhancing in friction value. This behavior related to the easy escape of water from contact area. The minimum value of friction coefficient was observed at 100% epoxy specimens. Maximum value of friction coefficient observed at 5% steel powder.

Electrostatic charge of epoxy flooring material filled by powder of aluminum chip is shown in Fig. 14. Electrostatic charge decreases with increasing aluminum powder content. Increase Al. powder help to conduct surface of epoxy floor to ground and disposal from electrostatic charge generated from friction. The minimum values of electrostatic charge were observed for 100% epoxy specimens. Increasing Al. powder content up to 3% show more effect in reduction of this charge.

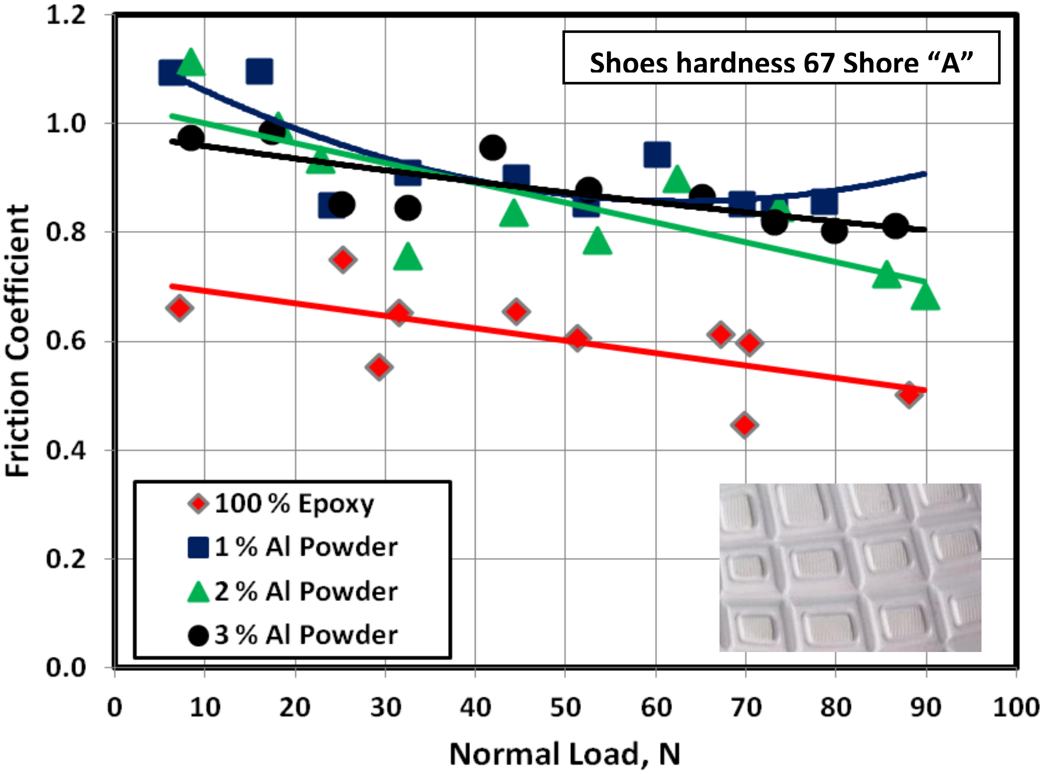


Fig. 12 Friction coefficient of rubber shoes with Hardness 67 shore A sliding against wet epoxy test specimens filled by Aluminum powder

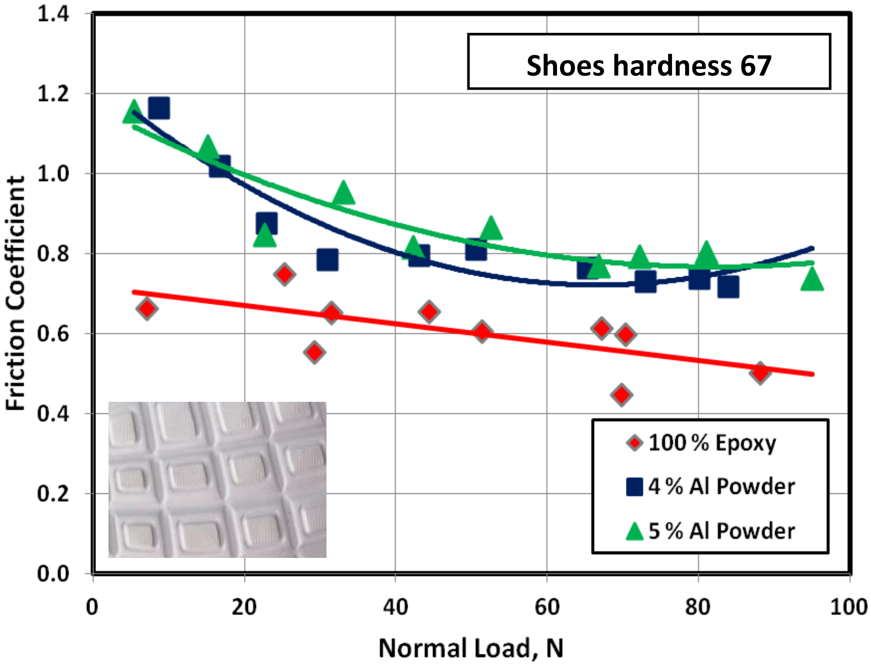


Fig. 13 Friction coefficient of rubber shoes with Hardness 67 shore A sliding against wet epoxy test specimens filled by Aluminum powder

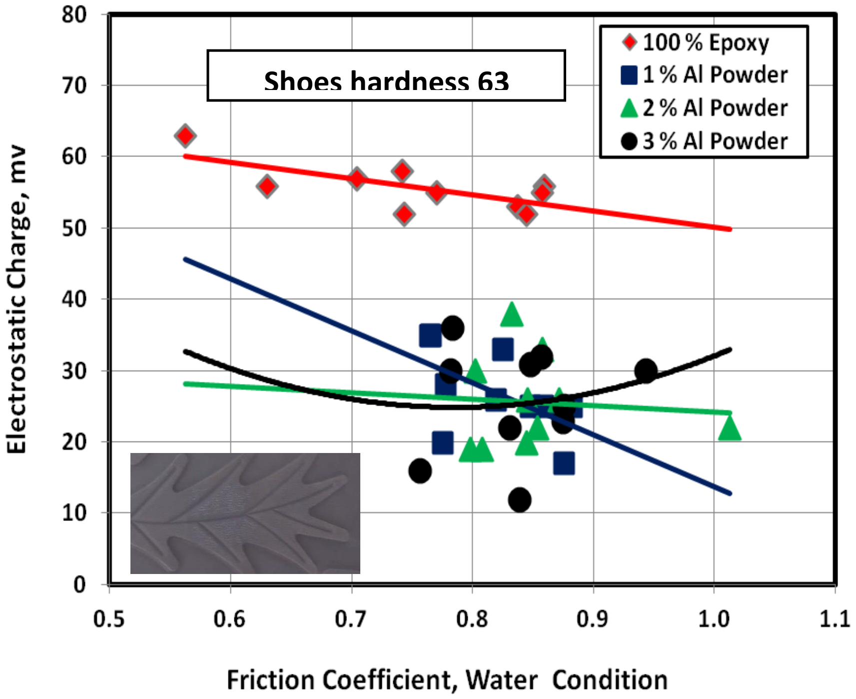


Fig. 14 Electrostatic charge of rubber shoes with Hardness 63 shore A sliding against wet epoxy test specimens filled by aluminum powder.

Figure 15 show the relation between electrostatic charge and friction coefficient, for epoxy test specimens filled by powder of aluminum chip. It can be noticed that the electrostatic charge decreases to minimum values at 5% Al. powder content. This behavior related to more effect of aluminum for disposal charge in presence of water. The minimum values of electrostatic charge displayed by epoxy floor filled by 5% aluminum powder.

Figure 16 show the relation between electrostatic charge and friction coefficient, for epoxy filled by powder of aluminum chip. It can be noticed that the electrostatic charge decreases with increasing steel powder content. This behavior may be related to increase the ability of aluminum to conduct and disposal this charge to ground. The water helped to distribution this charge on contact surface and easy for disposal through aluminum powder found in epoxy floor. The maximum value of electrostatic charge was observed at 100 % epoxy flooring. The minimum charge was observed at 3 % aluminum powder.

Increase powder of aluminum chip content in epoxy flooring is shown in Fig. 17. Electrostatic charge shows other decrease with increasing Al. powder content. Charge increases with increasing friction coefficient, this behavior enclosed on the fact of electrostatic charge generated from friction between two surfaces. The maximum values of electrostatic charge were observed at pure epoxy flooring material. Increase Al. powder content up to 5% show slightly increase in electrostatic charge. This behavior related to the converged of Al. particles and collect the charge without disposal from this charge.

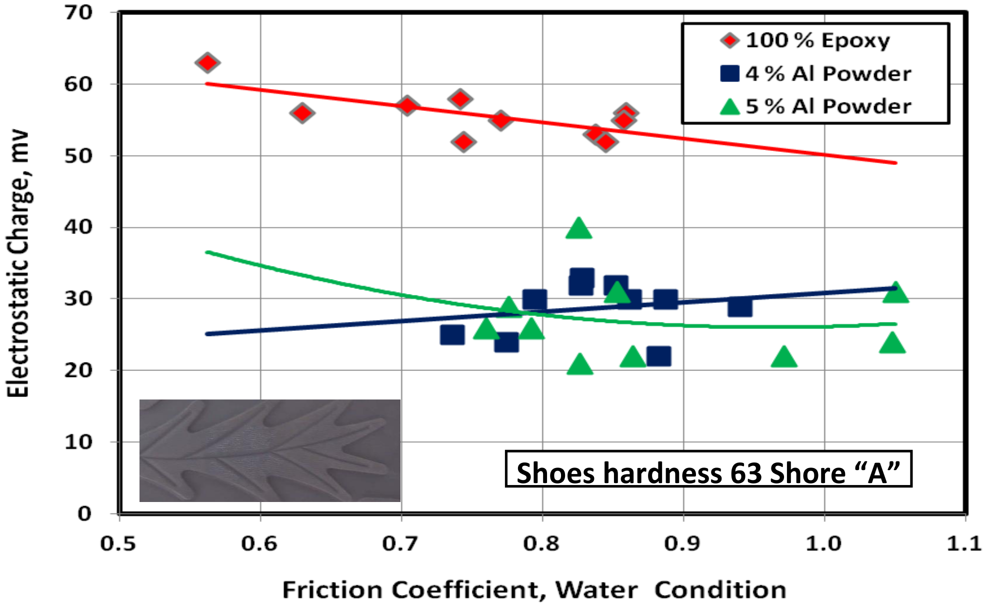


Fig. 15 Electrostatic charge of rubber shoes with Hardness 63 shore A sliding against wet epoxy test specimens filled by aluminum powder.

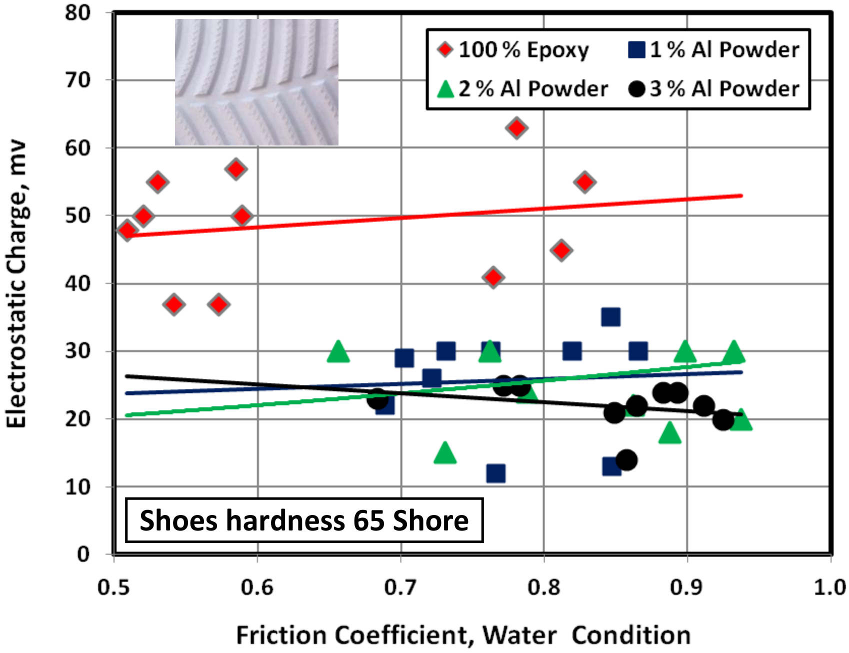


Fig. 16 Electrostatic charge of rubber shoes with Hardness 65 shore A sliding against wet epoxy test specimens filled by aluminum powder.

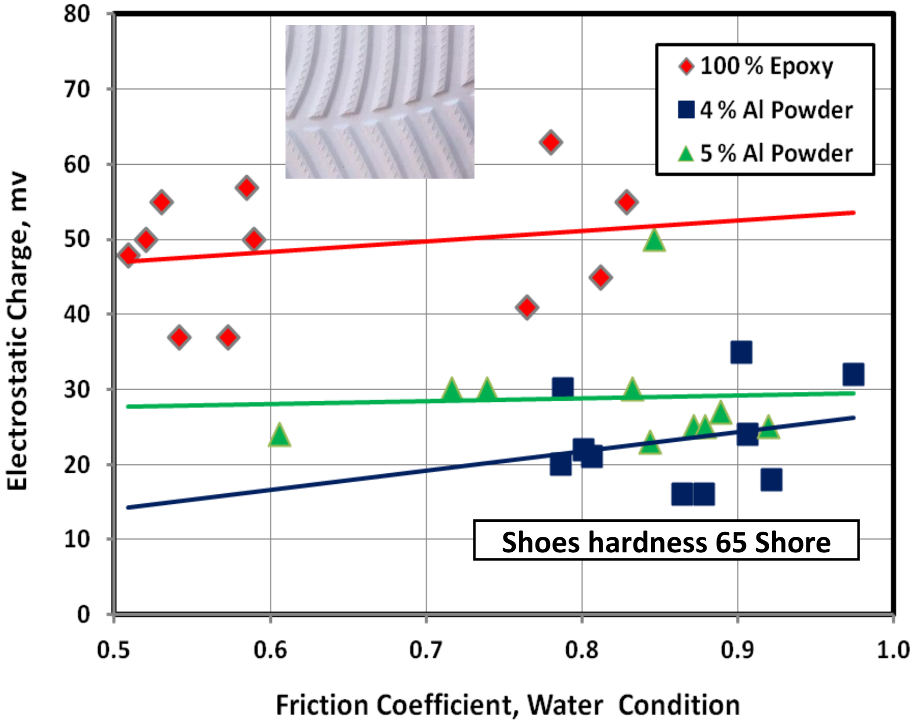


Fig. 17 Electrostatic charge of rubber shoes with Hardness 65 shore A sliding against wet epoxy test specimens filled by aluminum powder.

Electrostatic charge of rubber shoes sliding against water epoxy test specimens filled by powder of aluminum chip is shown in Fig. 18. Electrostatic charge decreases with increasing content of aluminum chip powder. This behavior may be related to decrease slipping of shoes on floor surface, as a result to decrease the electrostatic charge generated. The minimum value of electrostatic charge was observed at epoxy floor filling by 3% Al. powder.

Figure 19 show the relation between electrostatic charge and friction coefficient, for epoxy test specimens at 4% and 5% aluminum powder content. It can be noticed that the electrostatic charge decreased with increasing Al. powder content. Increase Al. powder content to 4% show significant reduction in charge. This behavior related to the good distribution of aluminum particles in epoxy floor and water distribute the charge on surface, this action help to easily disposal from electrostatic charge to ground. The maximum value of electrostatic charge was observed at 100% epoxy specimens.

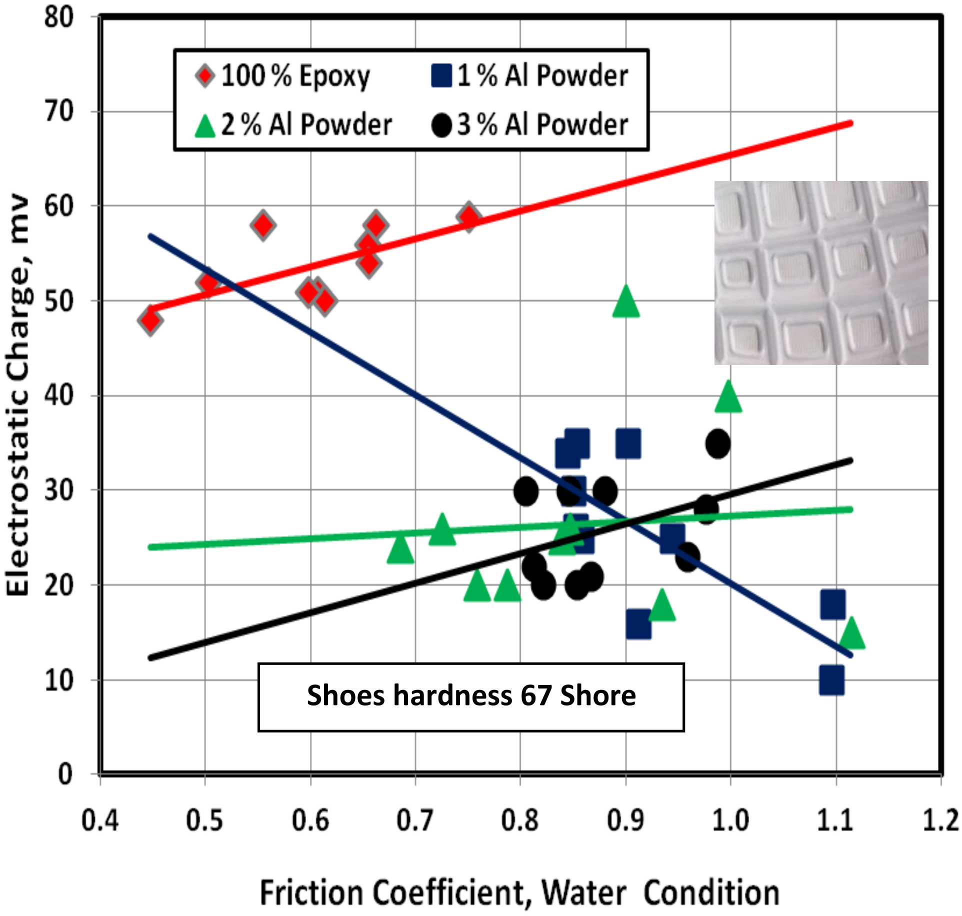


Fig. 18 Electrostatic charge of rubber shoes with Hardness 67 shore A sliding against wet epoxy test specimens filled by aluminum powder

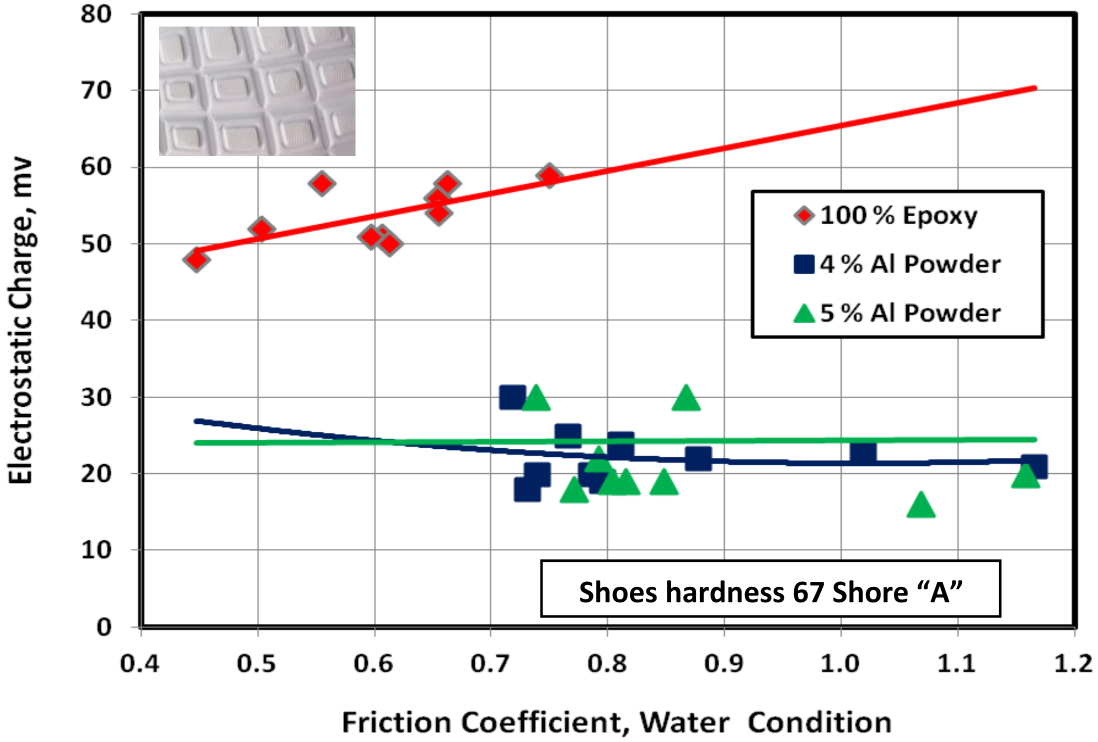


Fig. 19 Electrostatic charge of rubber shoes with Hardness 67 shore A sliding against wet epoxy test specimens filled by aluminum powder.

5 CONCLUSIONS

The safety of shoes increases with a decrease in the hardness of the shoe sole.

The friction coefficient increases with an increase in the aluminum powder content in the epoxy flooring material.

We recommend using aluminum machining chips to improve the safety of epoxy flooring materials.

Filling epoxy flooring materials with aluminum powder helps facilitate water drainage from the contact surface during walking, thereby enhancing floor safety, particularly in rainy weather conditions.

We recommend the safe disposal of machining chips to produce new products.

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تعزيز السلامة ومقاومة الانزلاق لمواد الأرضيات الإيبوكسي من خلال إعادة استخدام الرائش الناتج من تصنيع الألومنيوم

صالح الطاهر المريود[١]، عبدالرحمن خمج [١] ، عبدالله فقيهي [١] ، عمر طلال بافقية [١]، عبدالحليم محمود سامي [٢]

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مستخلص. هذه الدراسة هي جزء من مشروع بحثي واسع النطاق أجراه المؤلفون، والغرض الشامل منه هو إعادة استخدام الرائش الناتج من تصنيع الألمنيوم لتطوير خصائص الامان لمواد الأرضيات الإيبوكسية فيما يتعلق بمتطلبات السلامة ومقاومة الانزلاق بناء على قياسات الاحتكاك وتجنب خطر توليد الشحنة الكهروستاتيكية أثناء المشي.

يستخدم طلاء الأرضيات الايبوكسي بشكل شائع للأرضيات التجارية والصناعية. عادة ما يتم تطبيق طلاء الإيبوكسي على الأرضيات الخرسانية لتوفير سطح عالي الأداء وأملس ومتين يمكن أن يدوم لسنوات عديدة ويتحمل الأحمال الثقيلة. تعتمد العديد من المواقع الصناعية والمستودعات والمباني التجارية على أرضيات الإيبوكسي للحفاظ على بيئة عمل نظيفة وآمنة للعمال والمعدات والمخزون. اقترحنا إعادة استخدام الرائش الناتج من تصنيع الألمنيوم كمواد تعبئة لأرضيات الإيبوكسي من أجل زيادة معامل الاحتكاك وتقليل الشحنة الكهروستاتيكية الناتجة عن احتكاك الأحذية بمواد الأرضيات الإيبوكسي.

أظهرت نتائج الاختبار أن سلامة الأحذية تزداد مع تقليل صلابة نعل الحذاء. يزداد معامل الاحتكاك مع زيادة محتوى مسحوق الألومنيوم في مواد الأرضيات الإيبوكسية. يمكننا أن نوصي باستخدام الرائش الناتج من تصنيع الألومنيوم لتحسين الامان لمواد الأرضيات الايبوكسي. تساعد مواد الأرضيات الإيبوكسية التي يتم حشوها بمسحوق الألومنيوم الماء على الهروب من سطح التلامس أثناء المشي ، وهذا السلوك يزيد من سلامة الأرضية في الطقس الممطر. نوصي بالتخلص الآمن من الرائش الناتج من عمليات التشغيل لإنتاج منتجات جديدة.

الكلمات الرئيسية: الأمان ، الإيبوكسي ، معامل الإحتكاك ، الشحنة الكهروستاتيكية ، الماء ، مسحوق الالمونيوم.