# Characterization of Wear Resistance of Silica-Styrene-Butadiene Rubber Filled Hybrid Composites

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ABSTRACT— ***Composite materials are made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. In the present work a silica-styrene-butadiene rubber hybrid composite material is developed with 1 and 2 wt% of nano sized silica particle and 0.25 to 1.5 wt% of styrene-butadiene rubber mixed in resin. About 75% of wear reduction is found due to addition of silica particle, whereas addition of styrene-butadiene rubber has insignificant effect on the wear rate. However, it slightly increases the wear rate as compared to silica filled epoxy composite. Hybrid composites with higher silica content exhibit higher hardness. A good liner correlation between wear rate and hardness exists with probability $p <= 0.01$ and correlation coefficient $R > 0.8$.***

**Keywords—** Hybrid Composites, Wear Resistance, epoxy resin

## 1. INTRODUCTION

Composite are made up of individual material referred to as constituent material. There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. Most commercially produced composites use a polymer matrix material often called a resin solution. There are many different polymers available depending upon the starting raw ingredients. There are several broad categories, each with numerous variations. The most common are known as polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, polypropylene, PEEK, and others. The reinforcement or filler materials are fibers or inorganic particles of micron size to nano sized. Fillers are particles added to material to lower the consumption of more expensive material and to improve the mechanical properties of the resulting material. Among the 20 most important fillers, calcium carbonate holds the largest market volume and is mainly used in the paper industry and increasingly in the plastics sector.

Organic–inorganic hybrid composite materials are very important for their extraordinary properties such as mechanical, thermal, electrical, and magnetic compared to the pure organic polymers, which arise from the synergism between the properties of the respective components. Inorganic particulate filled epoxy matrix composites have been extensively studied during the last two decades due to their increasing applications in coatings, electronic packaging and dental restoratives [1-2]. The particles in these composites are generally of micrometer size. Use of nano particles as fillers in epoxy matrix composites is now a day attracting a great deal of attention from material scientists, technologists and industrialists [3-4].

Silica is one of the most applied fillers in polymer composites. Epoxy resin reinforced with silica particles having submicron dimensions represents one of the most studied systems. Already published results [5-6] evidenced that well dispersed silica nanoparticles can effectively enhance the comprehensive properties of epoxy-based nano- composites, which are unique and different from any other current conventional micro composite with typical filler amounts of less than 5 wt %. Various investigators reported that mechanical properties of silica particle/polymer nanocomposites are significantly enhanced even at very low particle volume fraction [7-9].

Styrene rubber resembles natural rubber in processing characterization as well as quality of finished product. It possesses outstanding properties such as high abrasion resistance, high load bearing capacity and resilience. Styrene-butadiene rubber can be used as filler material in addition to silica particle in order to enhance the mechanical properties and to reduce the overall cost of the material. It has been reported that silica particles dispersed uniformly within the rubber matrix [10] and enhances the mechanical properties of the hybrid composite significantly. The interaction between the rubber and the filler has been studied to determine the effects on failure of the compounds by many researchers [11-13]. Upon an applied load the rubber must bear the total strain; however, the local strain within the rubber phase is greater than the global strain attained by the system. This difference between the local and the global strains is termed the strain amplification factor. This aspect of the material is studied by stressing it at different strain rates. The interaction between the rubber and the filler affects the quasi-static properties of the compounds as well as the fatigue life. Inclusion of filler like silica into rubber and epoxy resin compounds serves to increase the modulus of the compound as well as hinder crack propagation. This reduction in the crack propagation occurs because of localized crystallization occurring in the compound due to regions of highly constrained polymer. These regions occur near the crack tip as well as in regions of high constraint due to the filler particles such as silica. Hence, appropriate proportion of silica-rubber mixed into the epoxy resin may increase the static as well as dynamic and fatigue properties of the hybrid composites. Keeping view of the above, the preset investigation is aimed to study of the microscopic structure and dispersion of filler material by scanning electron microscopy analysis and to established structure properties correlation, if any and to determine the mechanical properties of composite material like hardness, wear resistance, tensile strength, compressive strength, impact strength, etc. Mathematical models develop to determine, wear properties from the wt% of filler materials.

## 2. METHODOLOGY

Epoxy resin (CY 230), hardener (HY 951), silica particle and Styrene Butadiene Rubber (SBR) with different weight percentage of silica and SBR were used as received without further purification. Commercial epoxy resin CY 230 and hardener HY 951 were supplied by M/s Petro Araldite Pvt. Limited, Chennai, India and silica particle and styrene butadiene rubber were supplied by M/s Insilco Limited, Gajraula, ( Degussa Group) and M/s Taj Resins Pvt. Limited, New Delhi, India, respectively. Different mixtures of silica particles (particle content of 1 and 2 weight per cent), styrene butadiene rubber (0.25, 0.5, 1.0 and 1.5 weight per cent) and epoxy resin were prepared by mechanical stirring at 3000 rpm. The curing curve of epoxy CY 230 is shown in Fig.. 1. Based on the curing curve, the solution obtained by mixing silica particle and styrene butadiene rubber in resin is kept in the furnace at a temperature of 90 ± 10 °C for two hours [14]. At each interval of 30 minutes the solution is taken out from the electric furnace and remixed by mechanical stirrer at same speed. After two hours the whole solution is taken out and allowed to cool to a temperature of 45°C. When a temperature of 45°C has been attained the hardener HY-951 (8 weight per cent) is mixed immediately [14]. Due to addition of hardener high viscous solution is obtained which is remixed mechanically at high speed by the mechanical stirrer. The viscous solution so obtained is poured into different moulds for sample preparation for compression testing.

The identifying of the polymer was checked by its 1HNMR spectra recorded at 500 MHz. The signals at 7.3 ppm are indicative of aromatic protons which confirms the identity as styrene rubber. The signals at 6.7 ppm are due to attached CH protons to the aromatic system. The downfall shift is due to magnetic anisotropy because of its attachments to the aromatic system. The alifinic protons are at 5.4 ppm. All the above indicate identify of the polymer as poly styrene butadiene rubber (SBR) with Fig. no. 1.

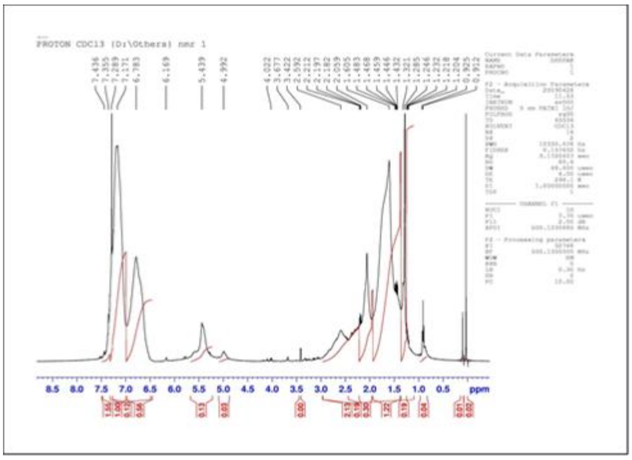

**Fig.1:** 1H NMR spectra recorded at 500 MHz

## 3. RESULTS

All the wear tests were conducted by using plint wear and friction testing machine (Sr. No.TE 97/705) fitted with Muyford super lathe, dead weight tester, transducer with calibration of 0.892 mv/v, microscope and chart recorder. The wear rate as calculated for the hybrid composites were plotted in Fig.s 2 & 3 against silica weight percentage and styrene-butadiene rubber weight percentage, respectively. All the tests were conducted at load 0.15 N/mm$^2$ and 1500 rpm.

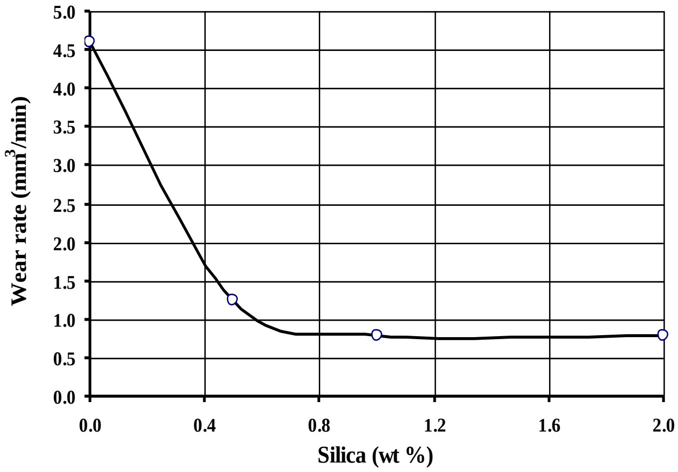


**Fig. 2:** Effect of silica wt% on wear rate at 1500 rpm speed and 0.15 MPa pressure

Fig. 2 shows that addition of silica particle is more effective in reduction of wear rate under 0.15 N/mm$^2$ of applied load. It is seen from the Fig. 2 there is about 85% of wear reduction due to addition of silica particle, which is about 1/5$^{th}$ times of pure epoxy. It is also evidence from the Fig. 2 that beyond 1 wt% of silica, there is no effective decrease in wear rate. Hence, it is can be concluded that particle content of about 1.0 weight percentage is seemed to be most effective in wear reduction.

Fig. 3 shows the effect of styrene-butadiene rubber on the wear characteristics of the silica filled composite material. Fig. 3 shows that wear rate increases due to addition of styrene-butadiene rubber both for 1.0 and 2.0 weight percentage of silica composite. The rate of increase of wear rate is more when the styrene-butadiene rubber weight percentage is less than 0.5 as compare to the higher weight percentage of styrene-butadiene rubber.

From the above discussion, it can be concluded that addition of silica particle of 132 nm size reduces the wear rate of unfilled epoxy significantly. The reduction of wear rate could be up to 5 times. The addition of styrene-butadiene rubber has insignificant effect on the wear rate. However, it slightly increases the wear rate as compared to silica filled epoxy composite.

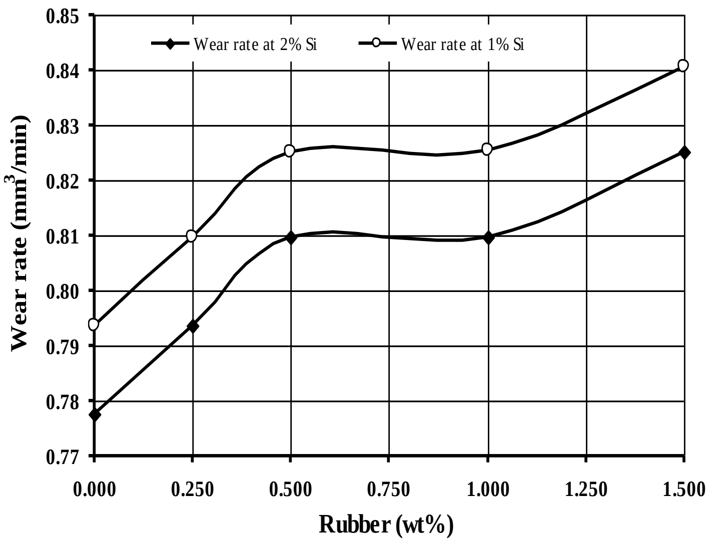


**Fig. 3:** Effect of styrene-butadiene rubber wt% on wear rate at 1500 rpm speed and 0.15 MPa pressure

The wear mechanism of particulate filled epoxy composite under the pin-on-disc condition has been discussed by [15]. The mechanism includes formation of cracks, development from cracks to waves and productions of debris.

Table 1: Wear rate ($mm^3$/min) for different wt% of silica and styrene-butadiene rubber at load 0.15 MPa and 1500 rpm.

| wt% Silica | Wear Rate ($mm^3$/min) | | | | |
|---|---|---|---|---|---|
| | wt% styrene-butadiene rubber | | | | |
| | 0 | 0.25 | 0.50 | 1.00 | 1.50 |
| 0.0 | 4.601 | - | - | - | - |
| 0.5 | 1.238 | - | - | - | - |
| 1.0 | 0.841 | 0.825 | 0.809 | 0.809 | 0.794 |
| 2.0 | 0.825 | 0.810 | 0.794 | 0.794 | 0.778 |

(-) not conducted

From the present observations it can be explained that with the addition of silica particle into the epoxy matrix, during the wear testing the formation and propagation of cracks are hindered to certain degree by the silica particles on or near the surface layer. This resulted in the formation of fine material waves and the formation of finer debris. Furthermore, the silica particles reduce the wear rate when the applied load is less than the critical one. Both of these contributed to the reduction of the wear rate of the epoxy matrix.

As it seen from SEM micrographs, the filler materials (i.e nano silica particle) uniformly distributed over the epoxy matrix. Hence, the mean distance between neighboring particles in case of 2 wt% silica particles is less than 1 wt% silica. Under lower particle contents, the dispersion of the particle in the epoxy matrix is good enough so that wear rate decreased as increasing of the particle contents. So, in the present investigation it is seen that the wear rate with 2 wt% silica content is less as compared to 1 wt% silica.

Addition of styrene-butadiene rubber increases the wear rate, but it is insignificant as compared to the effect of silica particle. The increase in wear rate due to addition of styrene-butadiene rubber may be due to increase in bonding strength between silica particle, styrene-butadiene rubber and epoxy matrix. Due to increase in bonding strength, formation of fine material waves and fine debris is less as compared to silica filled epoxy composite, due to which wear rate slightly increases due to addition of styrene-butadiene rubber.

Table 1 shows that wear rate of pure epoxy (CY-230) cured with hardener (HY-951) is 4.605 $mm^3$/min, which is about 4 times of the wear rate obtained in all hybrid composite containing silica and styrene-butadiene rubber. The wear rate for silica filled composite is about 0.825$mm^3$/min and for silica filled with styrene-butadiene rubber epoxy composite wear rate varies between 0.778 to 0.810 $mm^3$/min for different weight percentage of styrene-butadiene rubber.

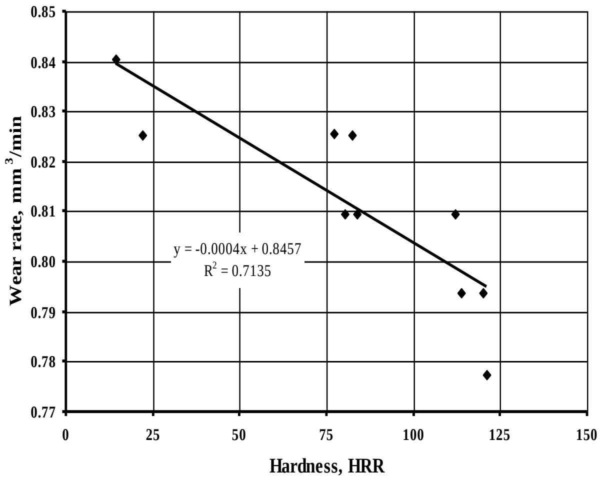


**Fig. 4:** Variation of hardness with wear resistance

To asses a possible correlation between surface hardness and wear resistance of silica styrene-butadiene rubber filled composites material regression and correlation tests were done. Fig. 4 shows the correlation between both. The R2 value of 0.7135 indicates a correlation and an inverse relation between them and student's test confirmed the correlation between the factor level with $p <= 0.01$ as value of 't' obtained is 4.574 and the tabulated value at 99% confidence level with 8 degree of freedom is t8, 0.01=2.0.

Hence, there is a linear relation between wear rate and hardness exists in the present investigation.

## 4. CONCLUSIONS

Addition of nano sized silica particles decreases the wear rate whereas styrene-butadiene rubber increases the wear rate. Over the 1.0 weight percentage of silica particles and 0.5 weight percentage of rubber, the reduction in wear rate is insignificant. A combination of 1 wt% of silica and 0.5 wt% of styrene-butadiene rubber decreases the wear rate upto 80% as compare to pure epoxy.

About 40% increase in hardness is obtained due to addition of 1 wt% of silica and beyond 1 wt%, there is no further increase in hardness. Adverse effects on the hardness due to addition of styrene-butadiene rubber have been observed. A good inverse linear correlation between wear rate and hardness exists.

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