The effect of carbon black filler to the mechanical properties of natural rubber as base isolation system

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Abstract. This paper presented the study on the effect of carbon black as filler to the mechanical properties of natural rubber for base isolation system. This study used the five formulations with the different amount of carbon black filler for every sample. The samples were tested for tensile, hardness and resilience test. The samples were cured or vulcanized at 1500C for 23 minutes for every formulation. The filler used in this study was the carbon black filler with type N660. The tensile test was done to determine the ability of the sample in term of the elongation with the load at break. The hardness test, it has been done to determine the ability of the sample to resist the load. This hardness was measured in the unit of IRHD. The resilience test was being done to determine the properties of the sample in term of rebound characteristics. The finding of this study showed that, the high the loading of carbon black filler, the high the tensile strength of the sample and the high the hardness of the sample. In term of resilience, it was inversely proportional to the loading of the carbon black filler.

1. Introduction

Rubber bearing is a device used to carry large vertical loads and provide significant horizontal flexibility. The rubber bearing used to captivate the vibration from any disaster. Even it cannot captivate the full vibration, but at least, this device can decrease the vibration and reduce the damage of the building. As known, on this present day, the construction of the high-rise building very high in number. This device consists of stiffness bearing that has been mounted on the foundation [1]. Rubber bearing also recognized as vibrator isolators. This system typically made from viscoelastic materials [2]. This device usually used in many applications in order to reduce the vibration. Other than be used high-rise building, it also normally used in the bridge project. The previous study said that this isolator base system was made from the mixture of the rubber with the other materials to make it more realistic and improve the device's capability[1-2].

Lately, the used of the rubber bearing devices is recognized globally. However, the former user of this devices found that the main materials that were cast-off to produce this isolation device show numerous bad effects in a long period of usage and also the devices were not given the full satisfied character has been inspected [3]. The common weakness of the rubber was the crosslink between the chains. This was been proof when it has been attacked by the huge external force, the chain was made the crosslink broke up [3]. The common effect was the aging of the rubber itself. Due to this problem, this research was initiated to examine the solution so that this device can be better. As this recent time, many researchers found that the enhancement to rubber formulation was significant [4-6].

There were a number of base isolator system types that have been cast off in the construction or building. There are two well-known of the base isolation system types, one of it is rubber bearing that is high damping rubber bearing (HDRB) and the other is lead rubber bearing (LRB) [7]. The earlier study shows that HDRB has the capability to make up the time period shift and also the energy dissipation. A layer of the rubber and some steel plate is the combine compounds in this rubber bearing that was bonded by the vulcanization. The base isolation system should attain the viscous damping for about 10% so that it can be used as the high damping rubber bearing. There were two types of rubber bearing, one of it is filed rubber bearing and the unfilled rubber bearing the another is filled rubber bearing and unfilled rubber bearing [8]. Filled rubber bearing is a rubber compound with the adding of the filler such as carbon or non-carbon filler. The example of the carbon filler was carbon black. This kind of filler usually used in the rubber compound. The examples non-carbon filler are silica and calcium carbonate. These fillers were grouped as the whitening filler. The purpose of the filler was to modify the properties of the rubber compound in the term of dynamic properties of the modulus and the hysteresis. Unfilled rubber bearing is the rubber compound without the addition of the filler. By using this unfilled rubber bearing, the application for the structure will be restricted because there was many flaws since the filler can give more enhancement to the application of the structure.

The main materials used to produce compound rubber bearing are natural rubber, streacid acid as co-activator, zinc oxide as an activator, filler carbon black, sulfur as a crosslink reagent and antioxidant. Natural rubber is flexible and is used positively in engineering applications for 150 years and stays the leading elastomer for springs and mountings. Natural rubber was chosen since it occupies a comparable locale alongside stare to rubber springs as spring steel does alongside metal springs. Most of the times rubbery materials are used for handling and lessen the undesirable level of vibration [9]. Silica(SiO_2) is one of the main reinforcing filler in the rubber industry [10]. The rubber that was normally used in the production of the rubber compound is nitrile rubber. Natural will be added to this type of rubber to make this rubber bearing increase its ability. This nitrile rubber (NBR) already used for the past 50 years [11].

Carbon black was the well-known filler that been used as filler in the filled rubber bearing. There were quite a few categories of the carbon black such as N330 (HAF black), N660 (GPF black), N550 (FEF black), N220 (ISAF black), and MT (medium thermal) black. It can use to increase the mechanical and the dynamic properties of the NR. The modulus and the abrasion resistance also can be improved. Besides the carbon black filler, there was alternative filler that was regularly used in the industry. These types of fillers were recognized as noncarbon filler that contained calcium carbonate, silica and magnesium silicate [12]. Among this noncarbon filler, the commonly used was the silica. The variances between the silica and carbon black were the level of reinforcement. The vulcanizing agent that acts as the crosslinking is required in order to avoid the rubbery polymer from sliding due to the stress. This was called as vulcanization. Based on the earlier study, this method will increase the forces and at the same time will decrease the permanent deformation after the force is detached. This method happens by mixing the crosslink to the polymer network. There were quite a lot of materials types can be represented as the cross-linking reagent such as metal oxide, sulfur, and the peroxide. Sulfur is the most normally used of the vulcanizing agent. In 1839, the process of sulfur vulcanization of rubbers was created by Charles Goodyear and as a result of his innovation, the rubber industry was explosively developed to this day [13].

2. Methods of research

2.1. Materials

The main ingredients to produce this rubber compound are the nitrile rubber, natural rubber, sulfur, the zinc oxide and carbon black (filler). The other materials also had been put to increase the capability of the rubber compound itself. The natural rubber used is the fresh rubber from the factory after a run through the procedure. The natural rubber used for this work was from the faculty of applied science produced by the Lembaga Getah Malaysia (LGM) located at Sungai Buloh Selangor. The type L natural rubber sample was used, meanwhile, the type of the nitrile rubber used was CBR.

Carbon black was the particle used acting as the filler in the form of powder. There were several types of carbon black that usually used for the rubber research. In this research, carbon black N660 was used.

Sulfur was used in this rubber compound due to its purpose as crosslink reagent. During the rubber compound formulation, the zinc oxide will perform as an activator. Besides that, this material will make the rubber compound more effective. This zinc oxide can be in the powder form. The samples prepared for this research is the mixture of the natural rubber and the other particle with different percentage of the carbon black filler. These samples had been vulcanized at a temperature of 1500C. Five samples had been prepared for the testing of this research. To produce this rubber bearing, the materials on the table below had been used. Table 1 shows the formulation of the samples of this which contained different amount of carbon black filler. Figure 1 shows the shows the laboratory work in the samples preparation.

Table 1. Formulation of samples

Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Natural Rubber (SMR L)	50	50	50	50	50
Nitrile Rubber (NBR medium ACN) (Krynac 833)	50	50	50	50	50
N660 (pphr) - Carbon Black	20	30	40	50	60
Zinc oxide	5	5	5	5	5
Stearic acid	2	2	2	2	2
Antioxidant TMQ	2	2	2	2	2
Sulfur	0.6	0.6	0.6	0.6	0.6
CBS	1.4	1.4	1.4	1.4	1.4
TMTD	0.6	0.6	0.6	0.6	0.6

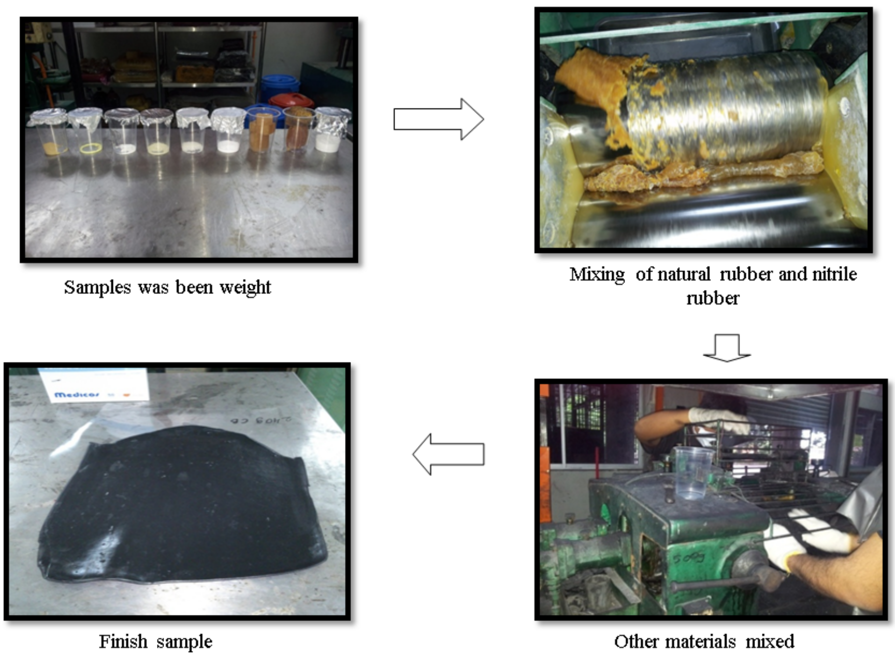

Figure 1. The steps for the samples preparation.

2.2. Testing
The rubber sample was tested with three different tests such as tensile test, resilience test, and hardness test. The standard method for determining the tensile properties is according to BS ISO 37:2011 [14]. The tensile test started by cutting the sample from compression machine into the dumbbell shape as shown in Figure 2. This procedure is done via the tensile sample cutter machine. After the sample been cut into the dumbbell shape, the center and the thickness of the sample need to measure and label. After that, the sample needs to be attached to the tensile machine using the clipper. Then the test started and stops instantly after the sample was cut up.

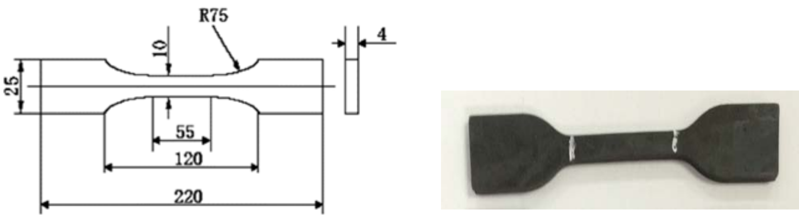

Figure 2. Sample for tensile test (all dimension in mm)

The rebound resilience was been conducted by using the sample with the circular shape (Figure 3). The sample was labeled with sample one and sample two. The test was held for three times to get the average value for the rebound resilience result for every sample. This hardness test was conducted by using the hardness testing machine (Figure 4). This test was conducted by putting the sample on the hardness test machine. This test was done three times for every sample. The test started at the center, right and left side of the sample to get the average hardness value of the sample.

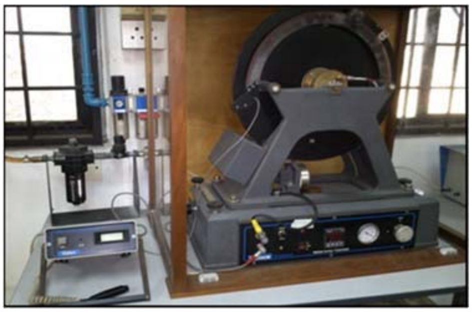

Figure 3. Rebound resilience test machine

Figure 4. Hardness test machine

3. Results and discussion

3.1. Tensile Test: Comparison the effect of different carbon black loading due to the stress at 100%(M100), 300%(M300) and 500%(M500)

Figure 5 and 6 show that the effect of filler loading to the stress of M100 and M300. It shows that loading of carbon black filler 60 pphr was the prime value which provides the high stress to the rubber bearing sample. Besides the 60 pphr of carbon black filler, it displays that the 50 pphr carbon black filler is the best selection if compare to the 20 pphr, 30 pphr, and 40 pphr itself. Referring to Figure 5, the high loading of black filler has 60pphr had the highest value of stress that was 4.69. In the meantime, the lesser loading of carbon black filler was the lowest stress was 1.71. Three of the sample that was 30pphr, 40pphr and 50pphrt the value of the stress was 1.78, 3.18 and 2.83 respectively. Figure 6, the high loading of black filler has 60pphr had the highest value of stress, which was 12.39. In the meantime, the lesser loading of carbon black filler was the lowest stress was 5.14. Three of the sample that was 30pphr, 40pphr and 50pphrt the value of the stress was 5.75, 9.77 and 8.73 respectively.

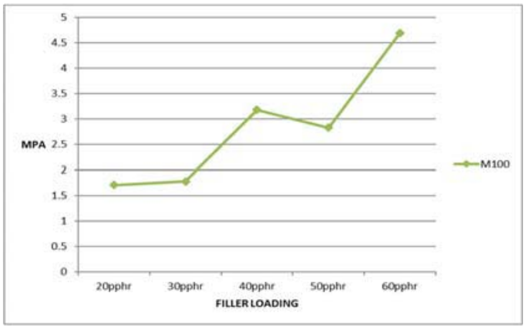

Figure 5. Effect of filler loading to the stress at 100%

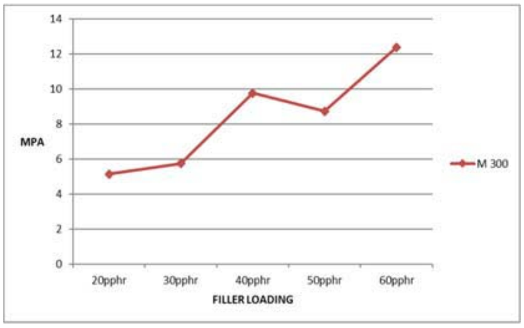

Figure 6. Effect of filler loading to the stress at 300%

Figure 7 shows that the result of filler loading to the stress of M500. It shows that loading of carbon black filler 60 pphr was not appropriate for modulus 500 to the rubber bearing sample. Besides the 60 pphr of carbon black filler, it indicates that the 50 pphr carbon black filler is the best decision if compare to the 20 pphr, 30 pphr, and 40 pphr. Figure 7, the highest loading of black filler that was 60pphr, there was no stress modulus.

In the meantime, the lesser loading of carbon black filler was the lowest stress, 12.64. Other three samples that were 30pphr, 40pphr, and 50pphrt presented the value of the stress was 12.68, 17.89, and 15.43 respectively. From the result, it shows the data for a sample of 50 pphr might be some error since the modulus should be increased by the increase of the carbon black filler. This might occur because of some fault in constructing this sample.

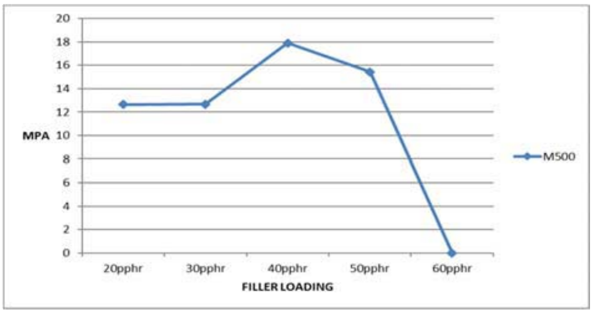

Figure 7. Effect of filler loading to the stress at 500%

3.1.1. Comparison the effect of the carbon black filler to the elongation @ break and load at break
According to the graph in Figure 8 and Figure 9, it can be see that the growth in the carbon black filler will cause the declining of elongation or break the rubber bearing sample. This occurred because when the rubber content in the mixture decreased, it will reduce the elasticity of the sample. One of the rubber properties was elastic. So, when the volume decreased and replace with the filler, the elasticity of sample will reduce directly. For this 20 pphr (80 g) of carbon black, the outcomes show the average for the elongation can be held by the sample was 628.57% from actual length of the sample at an average load of 199.4 N. The length of the elongation was contrariwise proportional to a load of a break.

For the 30 pphr carbon black sample, the elongation of the break was 635.63 % with the load of break 185.32 N. If comparing to the 20 pphr sample, the 30 pphr sample result not appropriate since the result of elongation should be less than 20 pphr sample. Then for the 40 pphr carbon black, the elongation of break and a load of the break were 547.70 % and 197.53 N respectively. In the meantime, for the 50 pphr, the elongation was 587.43 % and load at break was 174.44 N. Last but not least, for 60 pphr of carbon black, the elongation was 416.80 % with a load of break at150.83 N. The elongation of the sample was corresponding to the force exerted to the sample during the testing. In the graph above, the elongation for the 50 pphr of filler was high than 40 pphr, but it should be otherwise. This occurred perhaps throughout the producing of the sample; improper of weighing of filler might take place.

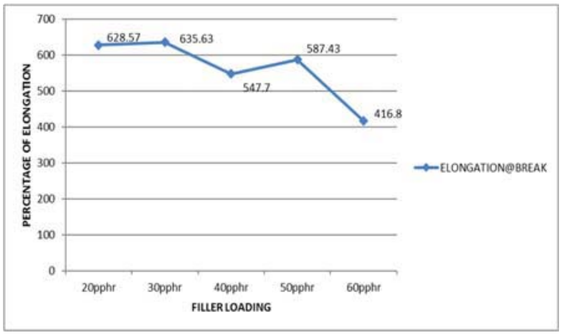

Figure 8. Effect of filler loading to the elongation at break.

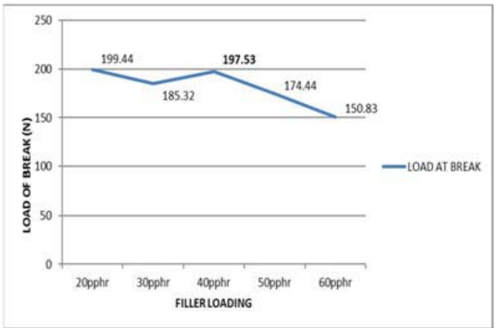

Figure 9. Effect of filler loading to the load to break sample.

3.1.2. Effect of the carbon black loading due to the tensile strength
Figure 10 shows the values of the tensile strength decrease by the increase in the filler quantity in the sample preparation. According to the theory of the research, the tensile strength graph should be in the S- curve graph. From the graph, the highest tensile strength of the sample was at 20 pphr carbon black with the value of 21.04 MPa. In the meantime, the lowest tensile strength for the sample was at 60 pphr with the 15.49 MPa. The optimum value of tensile strength was at carbon black loading of 40 pphr that

was 19.74 MPa. The other two samples that were at 30 pphr and 50 pphr got the tensile strength of 18.89 MPa and 17.82 MPa respectively. The values for the 20 pphr of carbon black filler have to be lower than 30 pphr carbon black filler. The result for the 20 pphr of carbon black filler has some error. The 40 pphr carbon black filler was the optimum loading to get the better tensile strength for the rubber bearing samples.

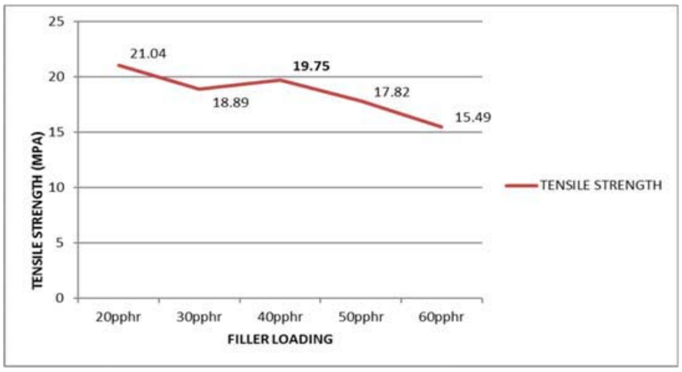

Figure 10. Effect of carbon black loading to the tensile strength.

3.2. Hardness test

Due to the ASTM, hardness was measured based on specified condition as the resistance to surface indentation. The test conducted by taking the average of measure in three different sample places; center, right and left side of the sample. The test conducted according to ISO 48 as a guideline. Figure 11 displays the best loading of the carbon black can be used as filler in the rubber bearing formulation was 60 phr. The hardness value for this 60 pphr carbon black was 81.83 for sample 1 and 81.67 for sample 2. The lowest hardness was the 20 phr of carbon black sample that was 47.17 for sample 1 and 47.5 for sample 2. In the meantime, the median hardness is 70.5 and 72.37 respectively for the sample with 40 pphr of carbon black for sample 1 and sample 2.

For the sample of 30 pphr, the hardness was 51.5 and 51.83 for the sample 1 and sample 2 respectively. Then for the 50 pphr for sample 1 and sample 2, the value of hardness was 66.0 and 67.67 respectively. Besides that, the bar chart also shows the hardness of the rubber bearing increase when the carbon black filler increase, but at 50 pphr the hardness of the rubber bearing decrease. According to the previous study, the hardness of rubber bearing wills increases by increasing the loading of the filler.

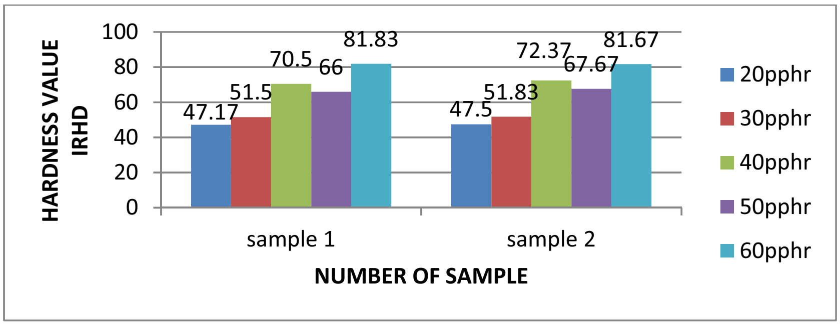

Figure 11. Bar chart for hardness.

3.3. Resilience Test

This test was run based on ISO 4662. The result can be calculated based on the following formula:

$$\text{Rebound resilience (\%)} = [\,1- \cos(\theta - \sigma 2)]/[1-\cos(\Phi-\sigma 1)] \times 100 \quad (1)$$

Where: θ = rebound angle, Φ = angle of drop (45), $\sigma 1$, $\sigma 2$ the damping correction for rebound and drop angle respectively.

In this paper, the research was just to find the effect of the filler loading to the rebound properties. According to the preceding study, the resilience of the rubber bearing should be inversely proportional to the filler loading. This is due to the high loading of filler, the high damping of the rubber bearing. According to the bar chart below, the resilience value for the 20 pphr carbon black was 57.93 % for sample 1 and 57.59 % for sample 2.

The lowest resilience was the 600 pphr of carbon black sample that was 35.56 % for sample 1 and 38.76 % for sample 2. In the meantime, the median resilience of the sample with 40 pphr of carbon black for sample 1 and sample 2 was 46.36 % and 47.46 % respectively. For the sample of 50 pphr, the resilience was 43.75 and 41.24 % for the sample 1 and sample 2 respectively. Then for the 30 pphr for sample 1 and sample 2, the value of resilience was 52.04 % and 49.79 % respectively. Due to the bar chart, the result was satisfied the theory from the previous study. The lower loading of filler was given the high resilience compares to the high loading of filler (figure 12).

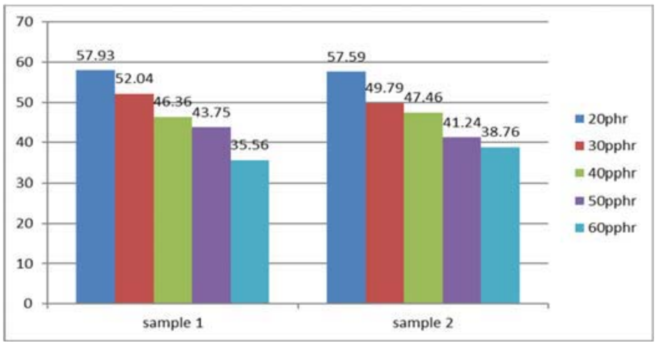

Figure 12. Bar Chart for Resilience Result

4. Conclusions

From the result, it can be concluded that the highest loading of carbon black filler used in the rubber bearing formulation gives the good effect to the sample as base isolation system in the tensile strength, hardness and rebound resilience. Referring to the graph of the tensile strength, the final data for the 20 pphr sample might be incorrect since it was high than other samples. This maybe due to the mistaken for weighing the materials of the formulation.

Besides that, for the hardness result, the hardness of the sample increase directly proportional due to the carbon black filler loading but, due to the graph of the hardness, at carbon black loading 50 pphr, the hardness was decreased. That should not be to occur. That might have been some fault of the sample. The error that potential can be was the exchanges of the sample during the compressing stages.

The lower carbon black filler with 20 pphr give the high percentage of the rebound resilience that was around 60 % compared to the high loading of carbon black filler that was given around 40 % rebounded resilience. From this result, it can be concluded that the high loading of filler gives high damping to the sample.

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