Repairing short shot defects in vulcanized rubber: A study on mechanical performance after compound addition

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Abstract. The rubber industry plays a crucial role in global manufacturing, with Indonesia being one of the leading natural rubber producers. One of the major processing defects encountered in rubber moulding is insufficient material loading, also known as a short shot, which can result in significant material waste and product rejection. This study investigates a repair method that involves adding a fresh rubber compound to patch defective rubber specimens. The method was applied by trimming a portion of the vulcanized rubber and replacing it with a fresh compound of the same formulation, followed by re-vulcanization. Mechanical properties, including tensile strength, elongation at break, tear resistance, hardness, and abrasion resistance, were evaluated following ASTM standards. Results indicated that repaired specimens generally retained acceptable mechanical performance, with abrasion resistance improving alongside increased patching percentages. These findings suggest that patching short-shot defects with fresh compound is a promising and cost-effective approach for reducing waste while maintaining product quality.

Keywords: rubber, short shot, repair method, mechanical properties, vulcanization

1. Introduction

The rubber industry plays a vital role in the global economy due to its wide-ranging applications across sectors such as automotive, construction, healthcare, and consumer goods (Lu et al. 2021). This is particularly relevant for Indonesia, one of the world's leading producers of natural rubber, which holds significant economic value and contributes substantially to the country's non-oil and gas export sector (Sya'bani et al. 2025). The unique properties of rubber, such as elasticity, durability, and resistance to wear, make it an important material in numerous industrial and commercial products.

Transforming raw rubber into finished goods typically involves the vulcanization process, which is essential for enhancing the material's mechanical and thermal performance (Cataldo

2023). Vulcanization achieves this by creating crosslinks between polymer chains, thereby improving elasticity, strength, and resistance to deformation (Traintinger et al. 2024). However, the success of this process depends on the precise control of several key variables, including temperature, curing time, pressure, and the amount of vulcanising agents. Careful regulation of these parameters is critical to ensure consistent product quality and optimal physical characteristics.

Despite careful control, errors during vulcanisation can lead to various defects in rubber products, such as under-curing, over-curing, surface imperfections, porosity, and dimensional inconsistencies. Among these, insufficient material also known as a short shot, represents a major defect that undermines the product's structural integrity and functional performance. Products affected by short shots are typically rejected as unfit for use as a final product that resulting in material waste (Lu et al. 2021).

To address short-shot defects, multiple strategies have been investigated, including fine-tuning processing parameters, optimizing mould design, and recycling the material as reclaimed rubber (Cataldo 2023). One practical and cost-effective approach involves adding rubber compound to fill in the deficient areas caused by insufficient material. However, this repair method remains underexplored, particularly regarding its influence on the quality and performance of the finished product. The success of this strategy relies on factors such as compatibility between the new and existing compounds, the bonding strength at their interface, and the effectiveness of subsequent vulcanization.

Considering its simplicity and potential to reduce production waste, the addition of a new rubber compound as a corrective measure for short-shot defects is a promising solution. Nevertheless, a thorough evaluation is required to confirm that this approach does not compromise the mechanical properties of the final product. Therefore, further research focusing on the mechanical characterisation of rubber products repaired through this method is crucial to validate its feasibility and potential for broader industrial applications.

2. Methods

2.1. Materials

The rubber compounds were made up of natural rubber SIR 3L, styrene-butadiene rubber, butylated hydroxytoluene, paraffinic oil, polyethylene glycol, zinc oxide, stearic acid, mercaptobenzothiazole, 2-mercaptobenzothiazole disulfide, tetramethyl thiuram disulfide, and sulphur. The detailed formulation and the amount of each materials cannot be disclosed due to confidentiality restrictions and the limited permission.

2.2. Rubber Compound Preparation

The compounding process was carried out in three sequential mixing stages: mastication, masterbatch mixing, and final batch mixing. During the mastication stage, raw rubber was placed on a two-roll mill and processed for 15 minutes until it reached a softened and workable consistency. In the subsequent masterbatch stage, additives including fillers, processing aids, plasticizers, antioxidants, and activators were gradually incorporated into the masticated rubber and mixed thoroughly for approximately 10 minutes to achieve a homogeneous blend. The final batch stage involved the addition of vulcanization agents, specifically accelerators and vulcanizing agents, which were mixed into the compound for 7 minutes. This process resulted in the formation of rubber compound sheets. The compound sheets obtained from the two-roll mill were then trimmed and cut according to the mould design pattern to prepare them for the subsequent forming and vulcanization processes.

2.3. Sample Preparation

The compound sheets obtained from the two-roll mill were trimmed and cut according to the mould design pattern in preparation for the moulding process. The cut rubber pieces were then shaped using a press moulding machine. During this stage, the compound was vulcanized at a temperature of 155 °C. The vulcanization time was set to 7 minutes for specimens intended for tensile and tear tests, while specimens for abrasion testing required a longer curing time of 30 minutes.

Following the moulding process, the vulcanized specimens typically exhibited excess material (flash) along the edges. This excess was carefully trimmed to produce clean specimen shapes. After the trimming process, each specimen was inspected to ensure it was free from defects or visible irregularities that could affect test accuracy.

Subsequently, the test specimens were further modified according to experimental percentage variables based on their total weight, from 10% to 90%, as shown in Table 1. For instance, in a 10% variable condition, if the specimen weighed 10 grams, then 1 gram of the material was cut and discarded. This step was applied to simulate material short-shot defects during the molding process.

2.4. Rubber Compound Addition

After the specimen trimming process, a repair procedure was carried out by patching the specimens with additional rubber compound of the same formulation. To prevent variations due to increasing crosslink density over time, the compound addition was performed at a similar time for all specimens (Lu et al. 2021). The amount of added compound was 20% greater by weight than the portion previously removed. For example, if 1 gram of material was removed, 1.2 grams of fresh compound were added as a replacement. The added compound was shaped and positioned using the mould pattern to ensure conformity with the original specimen geometry. The patched specimens then underwent a second vulcanisation using a press moulding machine at 155 °C, with a curing time of 7 minutes for tensile and tear specimens, and 30 minutes for abrasion specimens. Each test was repeated five times.

Table 1. Variation in rubber addition

Sample	New Compound Addition, %
RA-1	10
RA-2	20
RA-3	30
RA-4	40
RA-5	50
RA-6	60
RA-7	70
RA-8	80
RA-9	90

2.5. Rubber Testing

The mechanical properties of the vulcanized rubber were evaluated in accordance with ASTM D412-06 using dumbbell-shaped specimens. Tensile testing was conducted with a universal testing machine (Gester GT-K01). Hardness testing was performed using a Shore A durometer, following the procedures outlined in ASTM D2240. Abrasion resistance was assessed using an Akron abrasion tester (Gotech GT-7012-A), in which material loss due to friction was measured to evaluate the wear performance of the vulcanized rubber samples.

3. Results and Discussion

3.1. Visual Inspection

A visual examination was conducted on each specimen that had undergone the patching process. The results of this inspection revealed various types of surface defects, including uneven surfaces, bent or warped shapes, protrusions, and localized shrinkage as shown in Figure 1. These issues are likely attributed to several factors, such as inaccurate weighing of the compound, improper placement of the rubber compound within the mould cavity, or failure to adequately clean the mould before use.

(a) (b)

Figure 1. Defect on the specimen (a) uneven surface (b) shrinkage

Despite the occurrence of these defects, several specimens exhibited good visual quality, as illustrated in the representative images. Similarly, patched products may also achieve comparable outcomes, provided that the patching is done properly. Suppose the observed defects are limited to minor surface imperfections as described above. In that case, they may still be corrected during the finishing process, such as by trimming, polishing, or surface refinement, to achieve a more acceptable appearance and dimensional quality.

3.2. Mechanical Properties Testing

Mechanical testing of the rubber compound was conducted to assess its quality and ensure that it meets customer specifications and performance requirements. The evaluations included tensile strength testing, elongation at break, tear strength, hardness, and abrasion resistance. These tests provide a comprehensive understanding of the rubber compound's behaviour under various mechanical stresses and its suitability for end-use applications. The results were provided in Table 2.

Table 2. Mechanical properties of the rubber specimen

Per cent Addition, %	**Tensile Strength, N/mm^2**	**Tear Strength, N/mm**	**Elongation at Break, %**	**Abrasion, cm^3**	**Hardness, Shore A**
10	125.90	97.06	329.00	0.4990	62.50
20	132.39	76.96	355.25	0.4974	62.75
30	213.50	104.73	520.25	0.4687	64.50
40	204.73	102.00	518.50	0.3554	64.00
50	192.98	107.55	535.25	0.2962	64.00
60	206.84	89.40	545.50	0.2597	62.00
70	191.68	110.05	528.00	0.3201	64.50
80	202.50	104.55	511.50	0.2190	65.00
90	218.32	99.43	555.00	0.2706	65.50

The ability of the fresh compound to bond effectively with the previously vulcanized rubber plays a critical role in determining the final mechanical properties of the product, as illustrated in Figure 2. During vulcanisation, sulphur atoms form cross-link bridges between adjacent rubber chains, which contribute to the elasticity and strength of the material (Cataldo 2023). However, in repaired samples, the rubber undergoes a second heating cycle, which may alter the curing dynamics. The vulcanisation process itself consists of three phases: induction, curing, and post-curing. Prolonged exposure to heat during the post-curing phase can lead to a phenomenon known as reversion, where the established cross-links begin to degrade. This degradation can weaken the rubber matrix and negatively impact the mechanical performance of the final product (Traintinger et al. 2024).

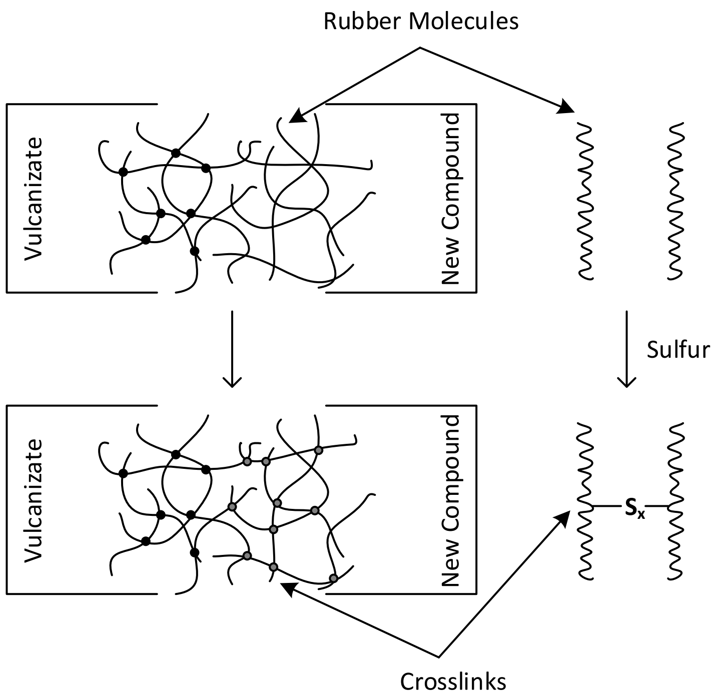
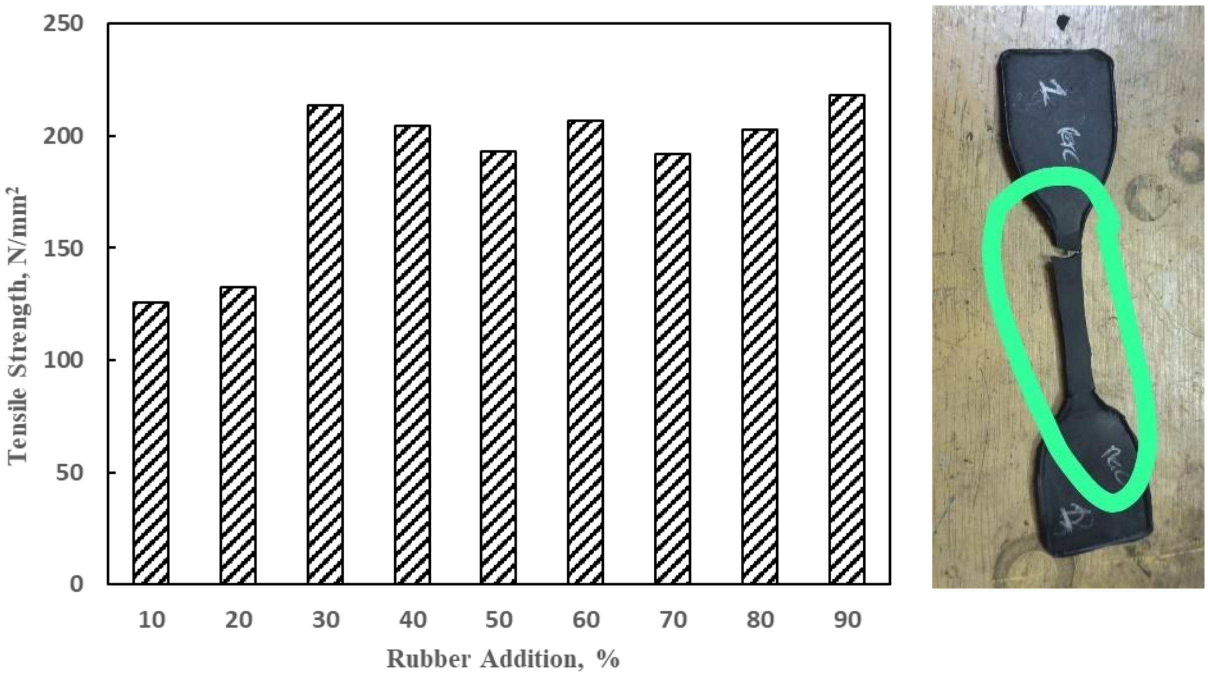


Figure 2. Potential crosslink between the new compound and previously vulcanized rubber

3.3. Tensile Strength

Tensile strength testing was conducted to assess the impact of the patching process on the mechanical performance of the rubber products. As shown in Figure 3, increasing the patching percentage generally contributed positively to tensile strength, although the trend was not strictly linear. The tensile values fluctuated across different patching levels. This behavior can be attributed to the fact that the fresh rubber compound more readily forms crosslinks compared to previously vulcanized rubber. Since tensile modulus is closely related to crosslink density, a higher proportion of the new compound resulted in greater tensile strength, reflecting the increased efficiency of crosslink formation (Han et al. 2020).



(a) (b)

Figure 3. Tensile strength of (a) the rubber vulcanizate (b) specimen

The lowest tensile strength was recorded in the 10% patching condition. This may be attributed to the position of the patch, which in this case was located at the centre of the specimen. As shown in Figure 3(b), the fracture occurred in the area surrounding the joint between the original material and the added compound, indicating a possible weakness in the bonding interface. Similar failure behaviour was also observed in several other specimens at different patching levels. The highest average tensile strength was achieved at the 90% patching level, with a value of 218.32 N/mm². This result suggests that, under certain conditions, patching can be effectively integrated without significantly compromising the tensile strength of the final product.

3.4. Tear Strength

The tear strength test results, as shown in the graph (Figure 4), do not exhibit a clear or consistent trend across the different patching percentages. The measured values ranged from 76.96 N/mm to 110.05 N/mm, indicating fluctuations that appear unrelated to the extent of patching. One plausible explanation is that the tear direction during testing was perpendicular to the patched interface, causing the tear to propagate primarily through the original material rather than along the joint. As a result, the influence of the patched area on the overall tear resistance was minimal. This suggests that the patching process did not significantly affect the tear strength performance of the vulcanized rubber specimens, particularly because the amount of vulcanization agents and the compounding and curing conditions were kept constant across all samples (Lu et al. 2021).

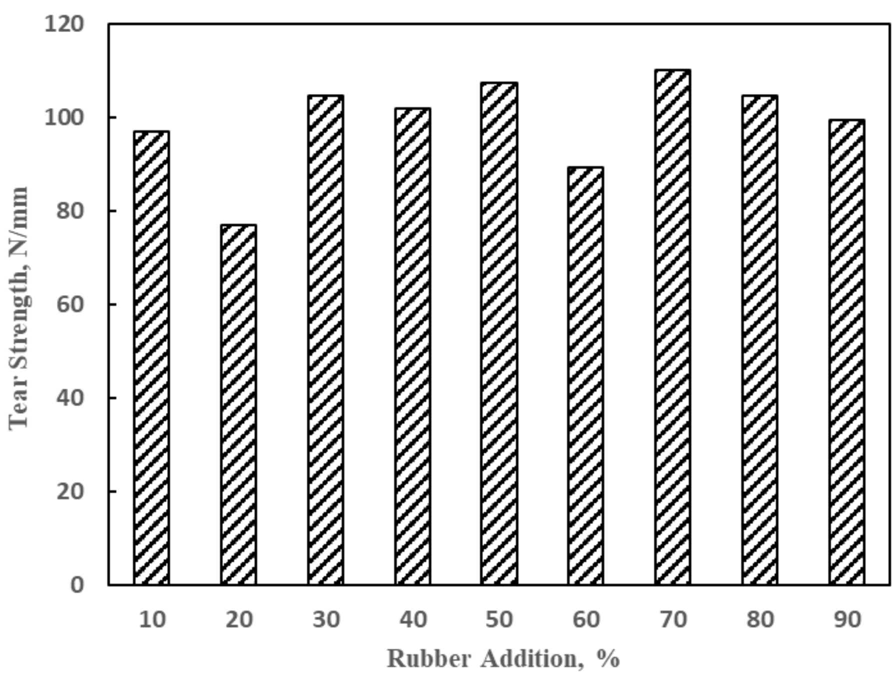


Figure 4. Tear strength of the rubber vulcanizate

However, further investigation using different tear angles or microscopic analysis at the tear interface could help determine whether microstructural discontinuities exist due to the patching process. Such analyses would provide deeper insights into the internal bonding quality and failure mechanisms associated with different patching levels.

3.5. Elongation at Break

Elongation at break is one of the key indicators of the elastic properties of rubber products. In vulcanized rubber, this property is strongly influenced by the degree of cross-linking within the polymer chains. As the number of cross-links increases, the molecular chains become less mobile, resulting in a decrease in elongation at break (Sya'bani et al. 2025). As shown in Figure 5, the elongation at break of the specimens tended to increase with higher percentages of compound patching.

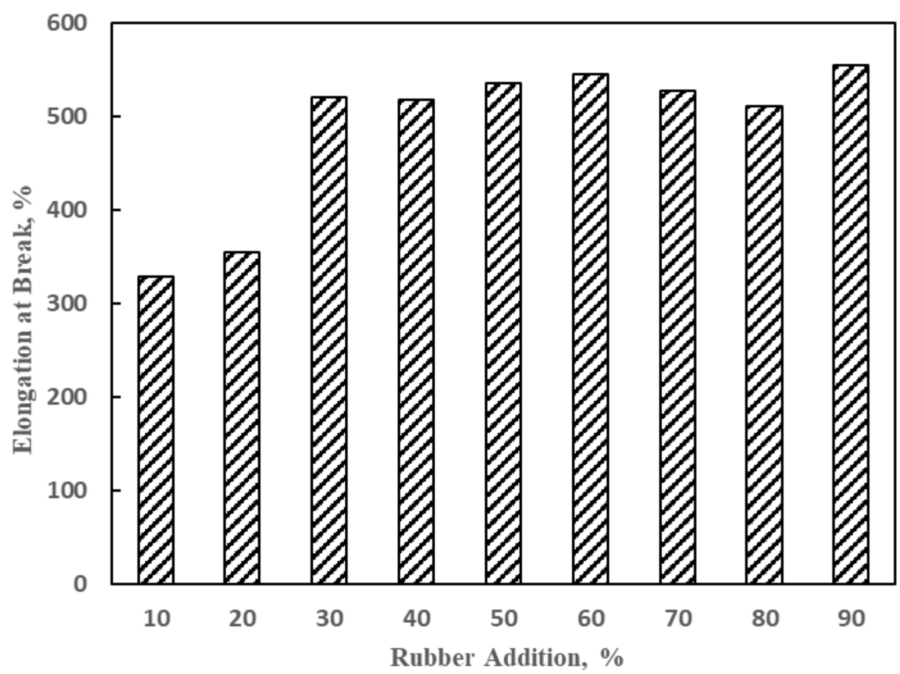


Figure 5. Elongation at break of rubber vulcanizate

Most of the values were found to meet or exceed the standard minimum requirement of 471.5%. A higher elongation at break value indicates greater elasticity of the rubber compound.

The highest elongation at break was observed in the 90% patching variable, reaching 555%, while the lowest value was recorded in the 10% patching variable, with only 329%. The lower elongation in the 10% patching condition may be attributed to the fact that a larger portion of the specimen (90%) had undergone repeated heating. This repeated vulcanization may have caused residual sulphur to form additional cross-links, thereby reducing the flexibility and elasticity of the material (Han et al. 2020).

3.6. Abrasion

Abrasion resistance is a critical property for rubber products that are subjected to friction or mechanical wear during their application. In this study, the test results showed a clear trend that the greater the amount of new rubber compound added to the patched specimens, the better their resistance to wear. This is indicated by the decreasing volume loss values recorded during the Akron abrasion test. Figure 6 shows the abrasion loss of rubber vulcanizate.

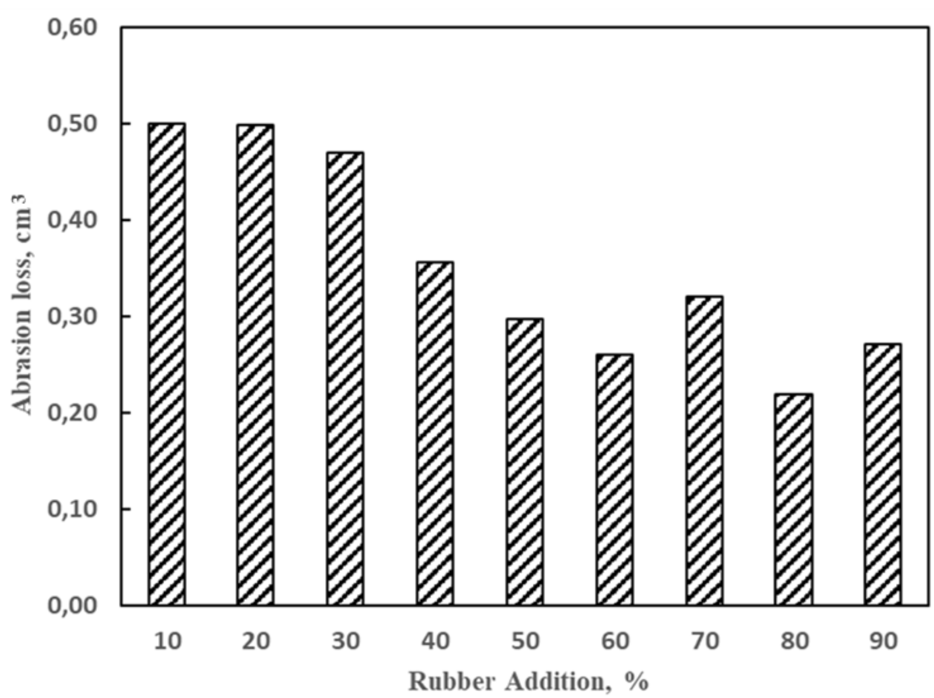


Figure 6. Abrasion loss of rubber vulcanizate

This improvement in abrasion resistance with increasing patch percentage can be attributed to the presence of fresher material that undergoes optimal vulcanization. The newly added compound likely forms more effective cross-links due to its chemically active state, which enhances the wear resistance of the overall material (Han et al. 2020). Abrasion resistance in rubber is significantly affected by the quality of cross-linking and the viscoelastic balance of the compound, so that fresher compounds that tend to offer more resilience under dynamic stress. (Allen et al. 2022). In contrast, specimens with lower patching percentages retained a larger proportion of previously vulcanized rubber that may have experienced a decline in properties due to multiple heatings. This may result in a less cohesive matrix with poorer wear resistance.

3.7. Hardness

Hardness is a measure of a material's resistance to localized plastic deformation. In rubber materials, higher Shore A hardness values indicate increased stiffness and rigidity. The hardness of vulcanized rubber is primarily influenced by the extent of cross-linking formed during vulcanization (Boonrasri et al. 2023). Additionally, the type and amount of fillers incorporated into the rubber compound can also significantly affect its hardness (Sya'bani et al. 2025). Greater cross-link density typically results in a stiffer, harder, and stronger rubber matrix (Tu et al. 2021). Figure 7 shows the hardness of rubber vulcanizate.

In this study, the hardness values of the specimens ranged from 62 to 65.5 Shore A, showing only slight variation between different patching percentages. This relatively narrow range is likely due to the use of the same rubber compound formulation for both the original and the added material, ensuring consistent material characteristics throughout the specimens. However, slight inconsistencies in hardness values across different sides of individual specimens were observed.

These discrepancies may be attributed to surface irregularities on some specimens, which can affect durometer readings. As illustrated in Figure 1, certain specimens exhibited uneven surfaces, potentially influencing the accuracy of the measured hardness.

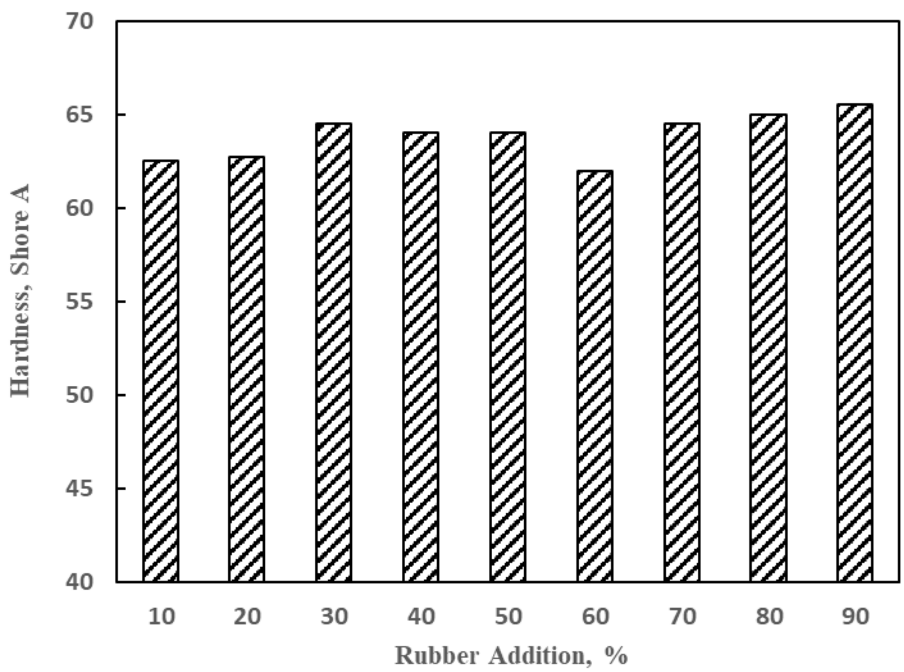


Figure 7. Hardness of the rubber vulcanizate

4. Conclusions

This study confirms that adding fresh rubber compound to repair short-shot defects is a viable and cost-effective solution, especially for reducing material waste in rubber manufacturing. Despite minor surface imperfections observed in some specimens, most repaired samples maintained acceptable visual and mechanical quality. Mechanical tests showed that patched specimens retained adequate tensile strength, elongation, tear resistance, hardness, and abrasion resistance. Notably, abrasion resistance improved with higher patching percentages, likely due to better cross-linking from the fresher material. These findings support the potential of this method for industrial applications, provided that process control and material compatibility are properly managed.

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