Jurnal
Teknologi

Full Paper

# THE MECHANICAL PROPERTIES OF CRUMB RUBBER STEEL FIBER CONCRETE (CRSFC)

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**Article history**
Received
*15 August 2023*
Received in revised form
*18 October 2023*
Accepted
*5 November 2023*
Published Online
*20 August 2024*

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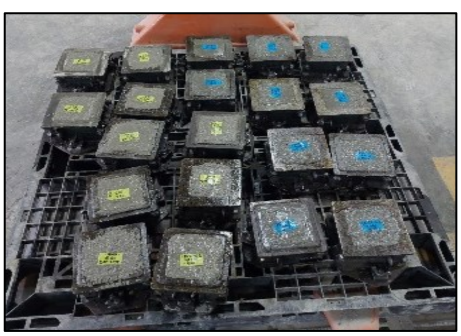
**Graphical abstract**



## Abstract

Waste materials can be used in concrete as part of replacement material. Currently, 4 billion tires are abandoned in landfills, with 1 billion generated annually and 1.2 billion dumped without treatment by 2030. The number of waste tires is continually increasing, because of the growing use of transport vehicles. Therefore, effectively reusing waste tires as crumb rubber in the mix of concrete can save energy and protect the environment, while the use of steel fiber in the concrete will help enhance its properties. The aim this research to producing the steel fiber crumb rubber concrete (CRSFC) and to balance the issues of strength loss and sustainability. Crumb rubber is used as sand replacement in the mix concrete in the following proportions: 0%, 5%, 10%, 15%, and 20%, while steel fiber is added in the following proportions: 0.5% by volume. Slump, compressive strength, dry density, water absorption, ultrasonic pulse velocity, and rebound hammer tests are performed on the concrete after curing. As the percentage of CRSFC increased, the slump value and dry density decreased while the water absorption increased. Steel fiber helps increase compressive strength by 33 % over normal concrete. The optimum percentage of crumb rubber in CRSFC as a sand replacement is approximately 5% to 10% by volume. In summary, incorporating crumb rubber and steel fibers into concrete can result in a more eco-friendly and resilient construction material.

*Keywords*: Crumb Rubber, Steel Fiber, Eco-friendly concrete, Mechanical Properties

## Abstrak

Bahan buangan boleh digunakan dalam konkrit sebagai sebahagian daripada bahan gantian. Pada masa ini, 4 bilion tayar ditinggalkan di tapak pelupusan sampah, dengan 1 bilion dijana setiap tahun dan 1.2 bilion dibuang tanpa rawatan menjelang 2030. Bilangan tayar buangan terus meningkat, disebabkan penggunaan kenderaan pengangkutan yang semakin meningkat. Oleh itu, penggunaan semula tayar buangan secara berkesan sebagai getah serbuk dalam campuran konkrit boleh menjimatkan tenaga dan melindungi alam sekitar, manakala penggunaan gentian keluli dalam konkrit akan membantu meningkatkan sifatnya. Matlamat penyelidikan ini untuk menghasilkan konkrit getah serbuk gentian keluli (CRSFC) dan mengimbangi isu kehilangan kekuatan dan kemampanan. Getah serpihan digunakan sebagai pengganti pasir dalam konkrit campuran dalam perkadaran berikut: 0%, 5%, 10%, 15%, dan 20%, manakala gentian keluli ditambah dalam perkadaran berikut: 0.5% mengikut isipadu. Kemerosotan, kekuatan mampatan, ketumpatan kering, penyerapan air, halaju nadi ultrasonik, dan ujian tukul pantulan dilakukan pada konkrit selepas pengawetan. Apabila peratusan CRSFC meningkat, nilai kemerosotan dan ketumpatan kering berkurangan manakala penyerapan air meningkat. Gentian keluli membantu meningkatkan kekuatan mampatan sebanyak 33% berbanding konkrit biasa. Peratusan optimum getah serbuk dalam CRSFC sebagai pengganti pasir adalah kira-kira 5% hingga 10% mengikut isipadu. Secara ringkasnya, menggabungkan getah serbuk dan gentian keluli ke dalam konkrit boleh menghasilkan bahan binaan yang lebih mesra alam dan berdaya tahan.

*Kata kunci*: Getah Serbuk, Gentian Keluli, Konkrit Mesra Alam, Sifat Mekanikal



## 1.0 INTRODUCTION

Recycled and waste materials are progressively can be used in concrete to overcome ecological threats and save energy. The potential for enhanced concrete properties, coupled with the ecological advantages of utilizing waste materials, motivates continued exploration into the development of eco-friendly concrete [1]. Concrete has become an increasingly engaging building material in recent years, as its characteristics have been enhanced using various additives and fibers.

Every year, around 1000 million trash tires are generated worldwide. By 2030, this amount is predicted to rise to 1200 million in future [2]. Tire disposal has become a worldwide issue. Burying old tires is a common disposal practise in many countries, which limits the service life of the burial ground and creates a significant environmental concern. As a result, successfully repurposing scrap tires is a critical issue for conserving energy and safeguarding the environment [2]. Figure 1 shows the waste tires disposal in Peninsular Malaysia (2011-2015) [3].

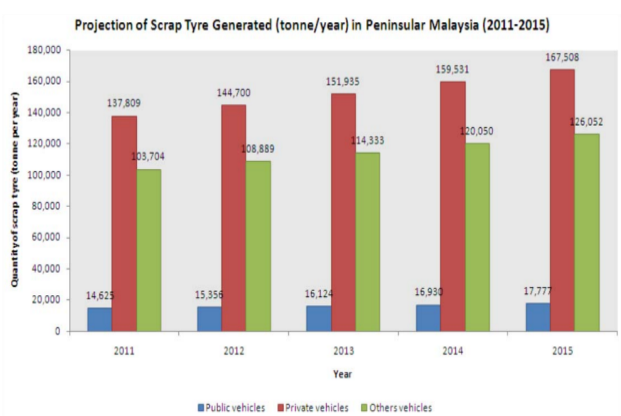



**Figure 1** Waste tires disposal in the in Peninsular Malaysia (2011-2015)[3]

Researchers have investigated using recycled scrap tires into concrete mixes as crumb rubber or rubber particles to improve ductility, toughness or energy absorption, impact resistance, fatigue resistance, and a variety of other properties [4]. When used in concrete mixtures, crumb rubber has a high elasticity, which promotes ductility and deformability. Previous studies have shown that using crumb rubber increases the damping ratio of the material, resulting in a low seismic response but a drop in compressive strength and elastic modulus [5].

The tensile strength, ductility, volume instability, and strength to weight ratio of ordinary concrete are all extremely low. The structure may fail due to damage. Concrete materials require a component that can boost compressive performance to resolve this concern. Steel fiber in concrete can increase flexural characteristics and has a long lifespan. Because of its elastic nature, crumb rubber may spread energy in general. It can absorb energy by preventing the crack from forming.

Steel fiber in concrete has a greater impact than standard concrete due to its superior properties. Prior study has demonstrated that inserting steel fiber into concrete mixtures enhances tensile strength, hardness, and energy dissipation, while also minimising surface cracking [5,6]. Research indicates that incorporating steel fibers into concrete improves the flexibility of structural components. The use of steel fibers in high-strength concrete helps prevent the formation of large cracks in concrete elements. After initial cracking, the presence of fibers results in higher residual strength and increased toughness in the concrete [6]. The steel fiber reinforced concrete is a complex composite material made up of steel fiber, cement, sand, and aggregate. Steel fiber concrete performance is directly connected to material qualities, the mix ratio, and maintenance circumstances [7]. Adding a certain amount of steel fibers (less than 5%) to concrete can lead to changes in physical properties such as resistance to cracking, impact, fatigue, and bending, as well as improvements in toughness, durability, and other characteristics [8]. Figure 2 depicts a sample of concrete that has been reinforced with steel fibers.

**Figure 2** Concrete with steel fibers [8]

As a result, mixing steel fibers with concrete to produce the fiber reinforced concrete is in high demand and has significant growth potential in the concrete industry. A new concrete that combines the advantages of concrete and fiber reinforced concrete.

The present study delved into the physical and mechanical properties of two types of concrete: normal concrete (NC) and crumb rubber steel fiber concrete (CRSFC). Through testing and analysis, the study was able to determine the optimum percentage of crumb rubber to be used in the CRSFC mixture to achieve the best results.

## 2.0 METHODOLODY

Crumb rubber, steel fiber, Portland-Limestone cement (PLC), coarse aggregate and sand were used in the production of concrete. The crumb rubber was obtained from Gcycle Tire Recycling Sdn. Bhd. in Sungai Petani, while the steel fiber was obtained from ECM Building Specialty Store in Selangor. According to the Public Work Department (PWD) Standard Specifications for Building Works 2020 [9], the nominal maximum size for aggregate is 20 mm and the nominal maximum size for sand is 5 mm. In this research, the crumb rubber used as a replacement for fine aggregates should pass through a 5 mm sieve. The steel fiber used is hooked-end steel fiber with an average length of 35 mm, a diameter of 0.55 mm, and a tensile strength of 1200 MPa, which is the commonly used steel fiber available in the Malaysia industry nowadays.

### 2.1 Preparation of Sample

For this research, 54 concrete cubes were used and divided into six samples, each containing plain concrete and CRSFC. The percentages of crumb rubber in each sample were 0%, 5%, 10%, 15%, and 20%, with 0.5% of steel fiber added by volume. The weight of the mix was calculated by volume, using a water-to-cement ratio of 0.45 and a 1:1:2 ratio (1 part cement, 1 part fine aggregate, and 2 parts coarse aggregate) .The amount of coarse aggregate used in this study was fixed. For casting, 54 concrete cubes measuring 100 mm x 100 mm x 100 mm were required.

**Figure 3** Crumb rubber as sand replacement

Each sample was poured into one of nine cube molds. Three cubes were cured for 7 days, three cubes were cured for 28 days, and three more cubes were cured for 28 days for the water absorption test. The concrete was allowed to dry completely for one day before being placed in the tank to begin the curing process. Table 1 shows the mixed concrete percentage design.

**Table 1** Concrete mix proportion design

| No | CR (%) | Sand (kg) | Cement (kg) | CA (kg) | SF (%) | W/C Ratio |
|---|---|---|---|---|---|---|
| NC | - | 5 | 5 | 10 | - | 0.45 |
| CRSFC 0% | 0 | 5 | 5 | 10 | 0.5 | 0.45 |
| CRSFC 5% | 5 | 4.75 | 5 | 10 | 0.5 | 0.45 |
| CRSFC 10% | 10 | 4.50 | 5 | 10 | 0.5 | 0.45 |
| CRSFC 15% | 15 | 4.25 | 5 | 10 | 0.5 | 0.45 |
| CRSFC 20% | 20 | 4.0 | 5 | 10 | 0.5 | 0.45 |

Note; NC; Normal Concrete,CR: Crumb Rubber, CA: Course Aggregate, SF: Steel fiber, W/C: Water-Cement

The steel fiber as illustrated in Figure 4, was obtained from ECM Building Speciality Store, Selangor. The steel fiber was used as an addition of 0.5% to the volume fraction. In this research, the type of steel fiber that was utilized was known as hooked-end, which was manufactured using a process called cold drawing. The hooked-end steel fiber had several key properties that made it suitable for this purpose, including an average length of 35 mm, a diameter of 0.55 mm (L/d ratio = 63), and a tensile strength of 1200 MPa. These properties allowed the fiber to provide the necessary reinforcement and strength to the concrete.

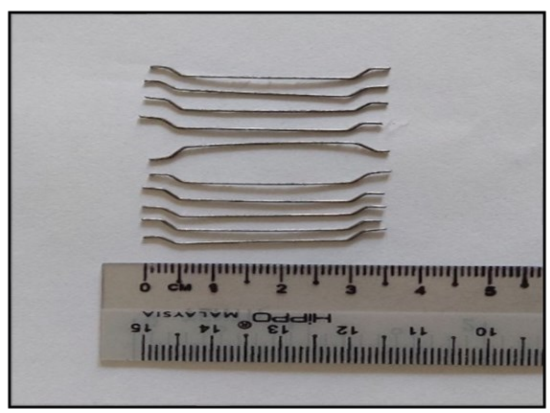


**Figure 4** Hooked-end steel fibers

## 3.0 RESULTS AND DISCUSSION

### 3.1 Slump Test / Workability

The slump test is a measure of the workability of fresh concrete, according to ASTM C143 [10]. The slump test was conducted to analyse the degree of workability of fresh concrete. The classification of the degree of workability is based on BS EN 12350-2:2009 [11]. From Figure 5 and Table 2, NC has better workability than the other sample that mixes crumb rubber and steel fiber.

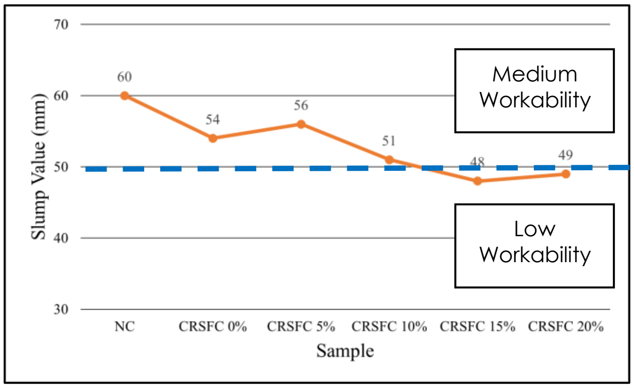



**Figure 5** Slump value

From the slump value, it can be concluded that the degree of workability for samples NC, CRSFC 0%, CRSFC 5%, and CRSFC 10% was medium, while samples CRSFC 15% and CRSFC 20% were low as tabulated in Table 2. For medium workability of concrete, suitable use normal reinforced concrete manually compacted. Since the slump value falls within the 30 mm to 60 mm range, all sample mixtures exhibit true slump. Decreasing workability as a result of increased friction between crumb rubbers (as proportion is added) and mortar and resulting in reduced particle flow; a critical factor affecting concrete mixing, placement, and finishing. Furthermore, because steel fibers improve the cohesiveness of concrete mixtures, slump values fall [12]. These findings proved that a larger water cement ratio is required for the rubber-based concrete mix than for NC to coat the crumb rubber particles and provide enough free water for proper cement hydration [13, 14].

**Table 2** Degree of Workability of Fresh Concrete

| Sample | Slump Value | Degree of Workability |
|---|---|---|
| NC | 60 | Medium |
| CRSFC 0% | 54 | Medium |
| CRSFC 5% | 56 | Medium |
| CRSFC 10% | 51 | Medium |
| CRSFC 15% | 48 | Low |
| CRSFC 20% | 49 | Low |

## 3.2 Water Absorption Test

Water absorption is a test that measures the amount of water that is absorbed by concrete over a specific period in accordance with ASTM C1585-20 [15]. From Figure 6, the absorption rate increased because the rubber had a bigger particle size than the fine aggregate. Due to a lack of fine components in the rubber particle, the difference in particle size resulted in additional voids. For samples NC and CRSFC 0%, they have the same percentage of water absorption after 28 days of curing, which is 5.78%. The sample CRSFC 20% absorbs more water compared to other samples, which absorb 7.49%, as it has the highest percentage replacement of crumb rubber. This result was in the range as indicated by previous researcher [16].Crumb rubber is a porous material that absorbs water and creates more pores in the concrete. Steel fibers can create a more permeable concrete matrix and microcracks in the concrete. The increased water absorption of concrete may be related to the production of small cracks and voids in the interfacial transition zone (ITZ) between crumb rubber and cement paste, which allows water to penetrate and flow [17]. The water absorption also decreasing with increasing of steel fiber as the concrete sample filled with solid steel fiber which reducing the void and pore capacity. This finding was similar with previous research by Yu Zhang Et. al. [18]

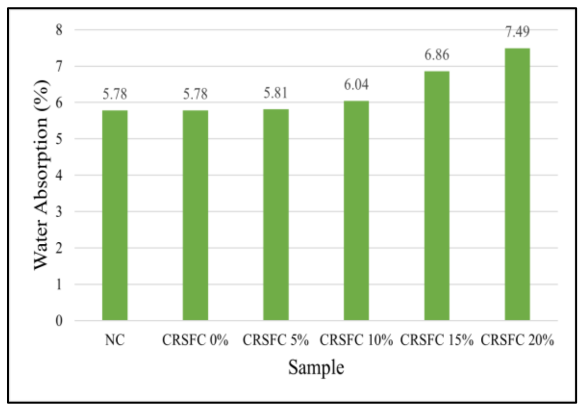



**Figure 6** Percentage of water absorption in sample

## 3.3 Dry Density Test

The dry density test was conducted to determine concrete compactness according to ASTM C138 [19]. Figure 7 shows the dry density result for the sample after 28 days of curing. As shown in the pattern of the graph, the dry density of concrete decreases when the crumb rubber is added according to its percentage replacement of fine aggregates. The normal concrete (NC) with an additive of 0.5% steel fibres has the highest dry density value, which is 2317 kg/m$^3$, compared to other samples. Meanwhile, the lowest dry density is CRSFC 20%, with a value of 1957 kg/m$^3$. The density and specific gravity of crumb rubber is lower in nature due to low unit weight, the percentage of crumb rubber in the CRSFC implies the dry density of concrete. The addition of crumb rubber to concrete mixtures increases the size and quantity of pores due to the rubber's hydrophobicity. The high number of holes lowered the density since it was later filled with air in a dry hardened condition, decreasing the density [20].The addition of steel fibre makes the concrete denser and stronger, as it is directly related to density.

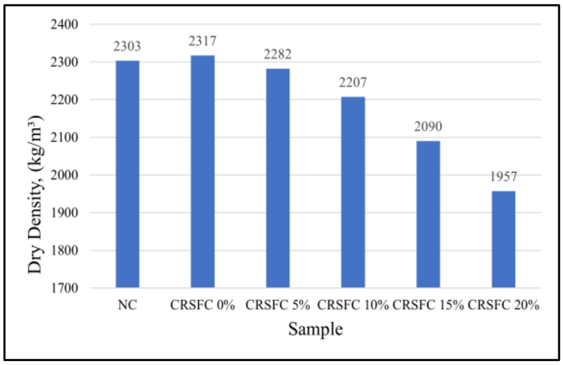



**Figure 7** Dry density of the sample

## 3.4 Compressive Strength Test

The compression test is a method used to evaluate the compressive strength of CRSFC and has been tested in accordance with BS EN 12390-3:2012 [21]. Based on Figure 8, it can be observed that for a sample of NC, the compressive strength was 30.76 MPa at 28 days. Then the compressive strength for sample CRSFC 0% has a higher value as it has increased by 41.05 MPa. Steel fiber enhances the static compressive strength of concrete, it increases it by 33% over NC. The addition of steel fiber improves the compressive strength, toughness, and fracture resistance of concrete [22]. After substituting of fine aggregate with crumb rubber in the mixture, the graph of compressive strength displays a downward trend. The amount of crumb rubber had a direct effect on compressive strength, with a higher percentage of crumb rubber resulting in greater reductions in compressive strength. Previous research has shown that compressive strength can be reduced by 10-59% [23]. Because of the smooth surfaces and softness of the crumb rubber particles, there was a considerable decrease in the adhesion between the cement paste and the crumb rubber particles, which increased the volume of the weakest phase and interfacial transition zone [24]. As the crumb rubber % rose, many fractures formed, resulting in specimen failure when force was applied [25].

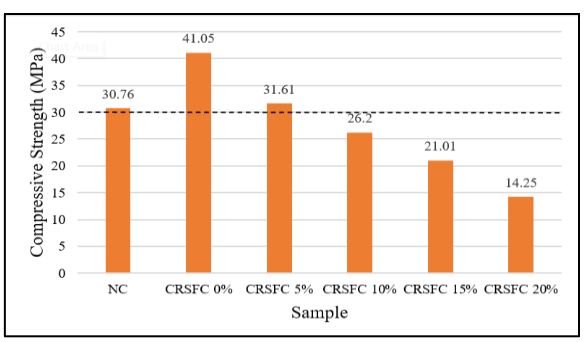



**Figure 8** Compressive strength for 28 days

## 3.5 Ultrasonic Pulse Velocity Test

The UPV test was performed on the sample after it had undergone 28 days of curing, in accordance with the ASTM C597-16 [26]. From Table 3 and Figure 9, the value of the pulse velocity for a sample of NC is 5.149 km/s. However, higher values of UPV for sample CRSFC 0% which is 5.155 km/s were observed compared to standard NC due to the utilization of steel fiber by adding crumb rubber particles to concrete mixes reduced the velocity of ultrasonic waves. The volume fraction of steel fiber appears to have little effect on increasing the UPV. In comparison to its impact on compressive strength, steel fiber has less influence on UPV. This reduction occurred due to the ability of rubber to absorb the waves. Moreover, the increase of crumb rubber in the matrix, impeded the ultrasonic waves and reduced the ultrasonic pulse velocity. However, crumb rubber gives another useful property for concrete in that it may limit sound transmission, which is one of the features for sound insulation. According to Nehdi and Khan's [27] applying rubber in concrete improves sound insulation over normal concrete. The sample CRSFC 20% has the lowest value of velocity, which is 4.629 km/s. The concrete quality of all the samples is excellent, as the value of pulse velocity is above 4.5 km/s [28]. As the velocity increases, so does the sample quality.

An excellent concrete quality implies that the concrete is free of significant voids or cracks that could compromise its structural reliability. The features of the rubber and the bond that exists between cement paste and rubber may be relevant for the significant rate reduction in the UPV [29]. As the density decreases, more air voids in concrete with crumb rubber will slow down the speed of the ultrasonic pulse

**Table 3** Concrete quality grading according pulse velocity value

| Sample | Average Pulse Velocity (km/s) | Quality of Concrete |
|---|---|---|
| **NC** | 5.149 | Excellent |
| **CRSFC 0%** | 5.155 | Excellent |
| **CRSFC 5%** | 5.101 | Excellent |
| **CRSFC 10%** | 5.051 | Excellent |
| **CRSFC 15%** | 4.952 | Excellent |
| **CRSFC 20%** | 4.629 | Excellent |

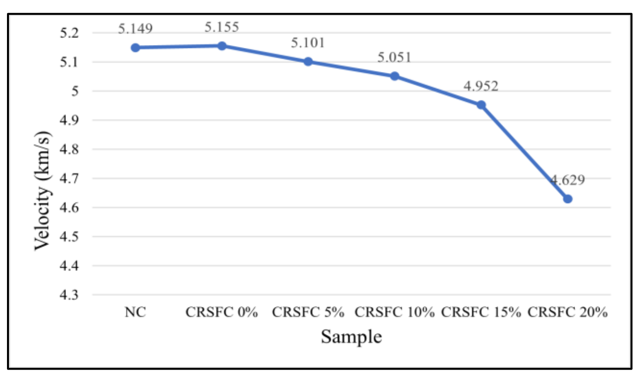



**Figure 9** UPV value of the sample

### 3.6 Rebound Hammer Test

The rebound hammer test establishes a good correlation between surface hardness and compressive strength according to ASTM C805-08 [30]. Based on Figure 4, the sample NC and CRSFC 0% have the same value of the rebound number, which is 15. The addition of rubber to the concrete increased the proportion of air voids, and because rubber is much softer than natural aggregates, it absorbs the energy generated by the hammer more than natural aggregates, resulting in lower rebound numbers and thus less strength. The reduction can be attributed to the crumb rubber functioning as a miniature spring within the concrete, absorbing some of the rebounding echoes [31]. This is because the rubber particles can deform and store energy when they are hit by sound waves. When the rubber particles return to their original shape, they release this energy as heat, which helps to dissipate the sound waves [32]. Figure 11 shows the relationship between the compressive strength and the rebound number of concrete.

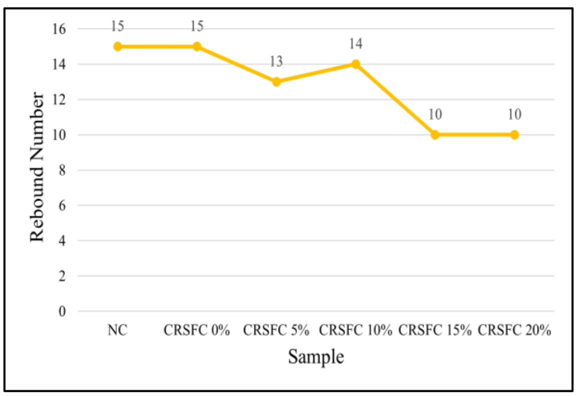



**Figure 10** Rebound number of the sample

The calibration curve of compressive strength versus rebound number is a graph that shows the relationship between the two properties of concrete.

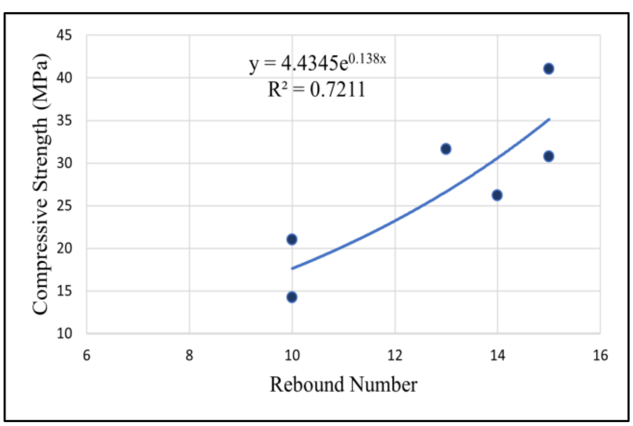



**Figure 11** correlation between rebound number and compressive strength

As shown in Figure 11, the $R^2$ value was discovered to be 0.7211. A $R^2$ of 0.7 or above is considered appropriate by most theoretical [33]. As a consequence, each exponential equation derived in this study produces satisfactory findings for the relationship between rebound hammer and compressive strength for rubber-concrete. There is a positive correlation between rebound number and compressive strength. Therefore, the observation that the rebound number decreased proves that there was also a corresponding decrease in the compressive strength of the concrete.

## 4.0 CONCLUSION

From the results, it was concluded that crumb rubber as sand replacement and the presence of steel fiber decreased the workability significantly. All the samples have a medium degree of workability except for the CRSFC 15% and CRSFC 20%, which have a low degree of workability based on the slump value. However, for water absorption, sample CRSFC 20% absorbs more water compared to other samples. The sample that contains 0.5% addition of steel fiber without any substitution of crumb rubber in concrete has a higher dry density, which is 2317 kg/m3.

The compressive strength of concrete for sample CRSFC 0% after 28 days has the greatest value, which is 41.05 MPa. Steel fiber helps it increase by 33% in strength over NC for grade 30. Incorporating rubber aggregate particles into NC and steel fiber concrete resulted in a reduction in compressive strength values. However 5% of sand replacement recommended to reach the minimum concrete grade (G30) for structural applications.The decrease in the rebound number indicates that the compressive strength has also decreased. The pulse velocity value is above 4.5 km/s, indicating that the quality of the samples is excellent.The decrease in the rebound number indicates that the compressive strength has also decreased. The pulse velocity value is above 4.5 km/s, indicating that the quality of the samples is excellent.

Based on the result, the optimum proportion of crumb rubber in CRSFC as a sand replacement is approximately 5% to 10% by volume. This percentage ensures that the concrete's strength and durability are maintained while also benefiting from the addition of steel fiber and crumb rubber. Steel fibers help to hold the concrete together and prevent cracking, while crumb rubber helps to lower the weight and increase the insulating qualities of the concrete. In summary, incorporating crumb rubber and steel fibers into concrete can result in a more eco-friendly and resilient construction material.

## Acknowlegement

We would like to thank to the Faculty of Civil Engineering and Technology Universiti Malaysia Perlis for their helpful feedback and support.

## Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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