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Engineering Properties and Impact Resistance of Kenaf and Rice Straw Fibres Reinforced Concrete

(Sifat-Sifat Kejuruteraan dan Rintangan Hentaman Konkrit Bertetulang Gentian Kenaf dan Jerami Padi)

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ABSTRACT

Natural fibre reinforced concrete (NFRC) has been a subject of interest for research in the past few decades due to the many advantages of natural fibres such as abundantly available, lightweight, cheap, diverse and as reinforcement in composite, provide great energy absorption and good impact resistance to the composite. The purpose of this paper is to study the engineering properties (workability, compressive, flexural and split tensile strengths, and impact resistance of NFRC, particularly kenaf (K) and rice straw (RS) fibres. Both fibres are investigated to determine feasibility of using abundant waste (RS) instead of kenaf (planted) as natural fibre reinforcement in concrete for impact resistance application such as roof tiles. Samples consist of untreated kenaf and rice straw fibres, with different percentages by volume of cement (0, 1, 1.5, 2, 3, 4 and 5%), as concrete reinforcement. The slump, compressive, flexural, split tensile strengths, and impact resistance are determined in accordance to BS, ASTM and ACI codes of practice. Results show that, due to high rate of water absorption of rice straw fibre, reduction in workability and compressive strength of RSFRC can be observed compared to KFRC. Increasing the volume of RS fibre leads to high volumes of entrapped air after curing process, resulting in decrease of concrete strength. However, addition of both fibres as reinforcement, enhanced the flexural, split tensile and impact resistance of concrete at up to a certain volume fraction of fibres. The energy absorption of RAFRC at 2% is superior compared to other fibres, except only coir and exhibit better performance in resisting impact even though kenaf has superior properties compared to RA due to its higher ductility compared to kenaf.

Keywords: Natural fibre reinforced concrete; kenaf; rice straw; mechanical properties; impact resistance

ABSTRAK

Konkrit bertetulang gentian semula jadi (NFRC) telah menjadi subjek penyelidikan yang paling menarik minat penyelidik sejak beberapa dekad yang lalu kerana gentian semula jadi boleh diperolehi dari sumber yang tidak terhad, ringan, murah, berkepelbagaian, bertindak sebagai penyerapan tenaga yang hebat dan mempunyai rintangan hentaman yang baik berbanding konkrit biasa. Tujuan kajian ini adalah untuk membandingkan sifat-sifat kejuruteraan NFRC seperti kebolehkerjaan, kekuatan mampatan, lenturan dan tegangan belah, dan ketahanan hentaman NFRC, iaitu yang mengandungi gentian kenaf (KFRC) dan jerami padi (RSFRC). Sampel konkrit bergentian terdiri daripada kenaf dan jerami padi yang tidak dirawat sebagai tetulang gentian konkrit, dengan peratusan isi padu berbeza berdasarkan berat simen (0, 1, 1.5, 2, 3, 4 dan 5%). Ujian kebolehkerjaan, kekuatan mampatan, kekuatan lenturan, kekuatan tegangan belah, dan ujian ketahanan hentaman dijalankan mengikut amalan kod BS dan ASTM. Keputusan menunjukkan bahawa disebabkan gentian jerami padi mempunyai kadar penyerapan air yang tinggi, dengan peningkatan isi padu gentian jerami padi, lebih banyak lompang terhasil selepas proses pengawetan. Oleh itu, penurunan kebolehkerjaan dan kekuatan konkrit dapat dilihat bagi sampel konkrit bergentian jerami padi berbanding kenaf. Penambahan kandungan gentian jerami padi telah menyebabkan kandungan udara terperangkap yang tinggi yang telah merendahkan kekuatan konkrit. Walau bagaimanapun, penambahan tetulang gentian semula jadi telah meningkatkan kekuatan lenturan, tegangan belah dan rintangan hentaman konkrit bergentian semula jadi ini sehingga satu peratus isi padu gentian tertentu. Tenaga penyerapan RAFRC pada kandungan gentian 2% adalah tertinggi berbanding lain lain gentian, kecuali gentian sabut kelapa. RSFRC juga menunjukkan prestasi tinggi dalam rintangan hentaman walaupun gentian kenaf mempunyai sifat sifat mekanik yang jauh lebih baik dari jerami padi disebabkan kemuluran gentian jerami padi yang tinggi.

Kata kunci: Konkrit bertetulang gentian semula jadi; kenaf; jerami; sifat-sifat mekanikal; ketahanan hentaman

INTRODUCTION

The most noticeable setback characteristics of plain concrete (PC) are brittle and weak in tension. The use of fibres to improve the tensile and flexural characteristics of construction materials can be traced back to earlier civilization. This includes early applications such as straw-reinforced into mud bricks, asbestos used in pottery and horse hair reinforced into plaster. The use of steel reinforcement in concrete contributes to strength and ductility, but it requires skilled labour, and the materials are expensive. Alternatively, introduction of fibre reinforcement in discrete form has provided a better solution. Modern development of fibre reinforced concrete (FRC) started in the early 1960s. More lightweight synthetic and ductile fibre such as glass fibre were developed. However, production of synthetic fibres are costly and consume high energy in their productions. In substitution for synthetic fibre, natural fibres were introduced. With almost similar properties as synthetic fibre, but cheap, and nature-friendly. Vast researches were conducted to utilize natural fibre as concrete reinforcement. Concrete added with fibres, makes it an isotropic and homogeneous material. When concrete cracks, the randomly oriented fibres arrest the crack formation and propagation, thus improve ductility and strength. Generally, FRC failure modes consist of both bond failure between fibres and matrix or material failure.

Al-Oraimi and Seibi (1995) investigated palm leaves fibres reinforced concrete and compared with glass fibres RC to study both impact resistance properties. They observed that palm leaves fibres enhanced the mechanical properties and impact resistance of concrete and exhibit comparable response to the glass fibres. Ramakrishna and Sundararajan (2005) studied the concrete impact resistance with some natural fibres such as coir, sisal, jute and hibiscus cannebinus (kenaf). The study found that the coir fibre reinforced concrete has the highest absorbed energy compared to the sisal, jute and kenaf. Udoeyo and Adetifa (2012) had studied the impact resistance of concrete kenaf cores with different fibre lengths. The results show that by increasing the percentage of kenaf fibre (KF) in the concrete, the absorbed energy decreased. In addition, the optimum fibre length for high energy absorption is 40 mm.

Cement-based composites reinforced by cellulosic fibres isolated from rice straw and bamboo showed a remarkable improvement in the mechanical properties, the flexural strength and the fracture toughness with increment of 24.3% and 45 times, respectively in the optimal sample. The bulk density of the composites decreased by 12.4–37.3% as a result of the introduction of cellulosic fibres (Xie et al. 2015). The large enhancement of impact resistance of FRC compared to PC has been reported either by incorporating synthetic fibre: polypropylene (PP) (Al-Rousan 2018); steel and PP or natural fibre (coir) (Al-Masoodi et al. 2016) and sisal (Pereira et al. 2015). They had shown that, natural fibre effect on impact resistance is at par with synthetic and steel fibres.

Based on Table 1, kenaf fibre has higher tensile strength and modulus of elasticity but low in ductility while RS fibre, low in tensile strength but high in ductility. The high percentage of elongation (ductile property) of RS fibre at breaking may contribute to the impact resistance compared to kenaf.

TABLE 1. Physical properties of rice straw and kenaf fibre

Properties	Rice straw	Kenaf
Density (kg/m^3)	30-40	1040
Elastic Modulus (GPa)	26	136 ± 25
Tensile Strength (MPa)	450	1000 ± 0.25
Ductility (%)	2.2	0.93-1.18
Water Absorption (%)	310-400	307
Reference	Reddy & Yang (2006)	Millogo et al. (2015)

In this paper, the workability, mechanical properties, impact resistance, and energy absorption of KF and rice straw fibres (RSF) reinforced concrete are investigated, and are compared with other natural fibres RC (NFRC) from previous researches.

METHODOLOGY

RAW MATERIALS

KF of grade V36 was supplied by Kenaf and Tobacco Industrial Board (LKTN) and planted in Pahang, Malaysia. After 1-3 days from harvest, kenaf plants undergo a water retting process for approximately 14 days to separate the skin from their stalks and later, cleaned with tap water and dried under the hot sun. After harvesting, rice straw are accumulated, left sun-dried in the field and later compacted and tied to be transported to RSF products. Both raw fibres were untreated and in dry condition. Kenaf and rice straw were cut into 20 to 40 mm and 15 to 40 mm length, respectively.

MIX DETAIL AND SAMPLE PREPARATIONS

Sieve analysis was carried out before hands to obtain the particle size distribution of granular materials. Preparations of all mixing batches are carried out carefully to achieve the required quality of final matrix, both PC and FRC. The FRC is normal strength concrete between 20 to 30 MPa while kenaf and rice straw act as fibrous reinforcement materials. Water per cement ratio for both FRCs were varies from 0.5 to 0.6 based on design and calculation of water addition during mixing. The concrete mixes for kenaf and rice straw were of 1: 2.6: 2.8 for mixes with kenaf, and 1: 2.3: 3.5 for mixes with RS, cement: fine aggregate: coarse aggregate, correspondingly. Mix design is based on DoE UK. Detailed mix design proportion is as shown in Table 2.

For all mixes, ordinary Portland cement Type 1, fine sand with maximum size of 4.75 mm, and coarse aggregate with 20 mm maximum size were used (ASTM C136 / C136M - 14 Standard Test Method for Sieve Analysis of Fine and Coarse

Aggregates). The strands of kenaf and straw with length of 20 to 40 mm and 15 to 40 mm, respectively were added by percentage of volume in multiples of 0.5%, from 1% up to 2% for kenaf and for rice straw, ranging from 1% up to 5%. Both fibres were randomly distributed.

TABLE 2. Detail concrete mix design

Sample	Water (kg/m^3)	Cement (kg/m^3)	Fibre (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)
K0%	190	352	Kenaf -	992	916
K1%	193	352	6.37	992	916
K1.5%	196	352	9.37	992	916
K2%	199	352	12.74	992	916
RS0%	190	317	RS -	1118	745
RS2%	192	317	6.6	1118	745
RS3%	193	317	9.9	1118	745
RS4%	194	317	13.2	1118	745
RS5%	195	317	16.5	1118	745

The mixing of concrete was standardised as follows: First, all the dry ingredients were mixed into the concrete mixer for one minute without the fibres. Then, water was added during the next two minutes to achieve consistency of wet concrete. Finally, the fibres were then added in small increments, by sprinkling them onto the surface of the mix until all the fibres had been mixed well into the matrix. This technique was performed to prevent ‘balling’ phenomenon or fibres interlocking.

Generally, for each mixing batch of concrete, it contained specimens of cube, beam and cylinder. For each specimen, it consisted of 3 samples for 7 days and 28 days testing. Every mixing batches consisted of 6 beams (100 ×100 × 500 mm^3), 6 cylinders (150 mm in diameter (Ø) × 300 mm in length), 6 cylinders (100 mm in Ø × 200 mm in length) and 6 cubes (150 × 150 × 150 mm^3).

A total of 180 concrete specimens consisted of beams, cubes and cylinders were produced for this study. All specimens were compacted by vibrating table, cured under water for 7 and 28 days, and tested at room temperature at 7 and 28 days.

EXPERIMENTAL PROCEDURE

WORKABILITY

The workability of fresh concrete mixes for each mix batch was determined using slump cone apparatus in accordance to BS 1881:102 (Testing concrete: Method for determination of slump) codes of practice. Each value represented the slump of each mix batch.

MECHANICAL PROPERTIES

COMPRESSIVE STRENGTH TEST

The compressive strength of concrete was determined using compression machine in accordance with BS 1881: 116 (Testing concrete: Method for determination of compressive strength of concrete cubes) codes of practice. Each value represented the average of three samples.

FLEXURAL STRENGTH TEST

The flexural strength was determined using third-point flexural test in accordance with BS 1881:118 (Testing concrete: Method for determination of flexural strength) codes of practice. Each value represented the average of three samples.

SPLIT TENSILE STRENGTH TEST

The split tensile strength was determined using compression machine in accordance to BS 1881: 117 (Testing concrete: Method for determination of tensile splitting strength) codes of practice. Each value represented the average of three samples.

IMPACT RESISTANCE AND ENERGY ABSORPTION TEST

The impact resistance and energy absorption are determined from drop-weight impact test in accordance with ACI 544.2R-89 codes of practice technique. Each value represented single sample. The concrete samples were Ø100 mm × H200 mm cylinders. Prior to testing, the samples were taken out of the water tank and were dried first. The weight of the steel ball was 2.175 kg and was set at 240 cm high from the floor before being released to fall freely by gravity. Concrete sample was placed on the floor in the baseplate. The readings were taken for the number of impacts required to crack the sample. The hammer was dropped repeatedly, and the number of blows required to cause the first visible crack on the top and to cause ultimate failure were both recorded. Ultimate failure is defined as the opening of cracks in the specimen sufficiently so that the pieces of concrete are touching three of the four positioning lugs on the baseplate. The energy absorption is calculated using Equation 1, given as:

$$E = mg(H_1 - H_2)n \tag{1}$$

where:

m = weight of steel ball
g = force of gravity
H_1 = height of steel ball
H_2 = sample height
n = the number of impacts

RESULTS AND DISCUSSION

The results showed that with addition of rice straw (current study) and oil palm trunk natural fibres (Ahmad et al. 2001), the slumps of mixes decreased (Figure 1). This is due to fibres high rate of water absorptions for both fibres (Table 1 for RS) that take some amount of water from the concrete mixes, thus reducing the workability of freshly mixed concrete. However, for kenaf fibre RC (KFRC) mixes, the workability increased, even though the water absorption of kenaf is nearly the same as RS (Refer Table 1). This is due to the effect of kenaf fibre physical properties that are denser and have less hollow sections (high density, tensile strength and stiffness). Therefore, increase in workability can be observed from addition of kenaf fibre. The workability of KFRCs maintain at 120 mm at all volumes of kenaf. Among the three fibres, kenaf is the lowest water absorbing material.

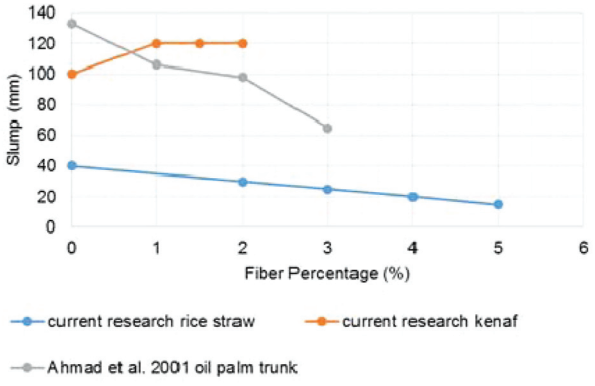

FIGURE 1. Slump of mixes at various percentages of fibres volumes

Figure 2 shows that the compressive strengths of FRCs are higher at lower percentage of fibres. As higher fibre volumes are added, the compressive strengths start to decrease. Increasing the volume of fibre leads to high volumes of entrapped air after curing process, resulting in decrease of concrete strength. In the current research, at 2% volume fraction of kenaf fibre, the KFRCs still increasing in strength, indicating that 2% is not the maximum value, with more tests of mixes at volume percentage higher than 2% need to be done to confirm the maximum value for this mix design (Grade 15 of control). For another KFRC mix design by Isman (2011) (Grade 25 of control), the optimum value is 4%. However at higher strength of concrete (Grade 35 of control), Lam and Jamaludin (2015) results show varied pattern, one being the compressive strengths of mixes (0.5 and 0.75% volume) increase higher than control and the other decrease at all fibre contents. For RSFRC mixes, the compressive strengths reduce at all volume percentages of fibres. There is no typical pattern for volume percentages of natural fibres to increase the compressive strengths, which largely depends on the water absorption of fibre and water per cement ratio, but observing Figure 2, it can be concluded that fibre content of fibres can be between 0.1% up to 4% only to be effective in increasing compressive strength of natural FRC.

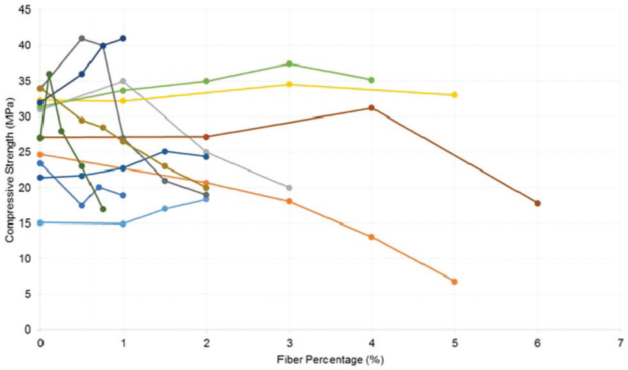

FIGURE 2. Compressive strength of KFRC and RSFRC compared to other NFRCs

Figure 3 shows that the flexural strengths of all FRCs increase with addition of natural fibres. This is because the fibres have effectively arrested the crack formation and propagation in flexural load, thus improving the ductility and flexural strength of FRCs. The optimum volume fraction vary from one fibre to the other. For kenaf, in current research, 2% volume of fibres shows highest flexural strength at increasing rate, indicating 2% is not the maximum value. Isman (2011) showed that 4% as the optimum value and at higher strength (Grade 35 control), the optimum value of kenaf fibre volume is only 0.75% (Lam & Jamaludin 2015). This shows that, at low water per cement ratio, lower amount of kenaf can be added so that the mixing water is available for hydration process without being absorbed by the kenaf fibres.

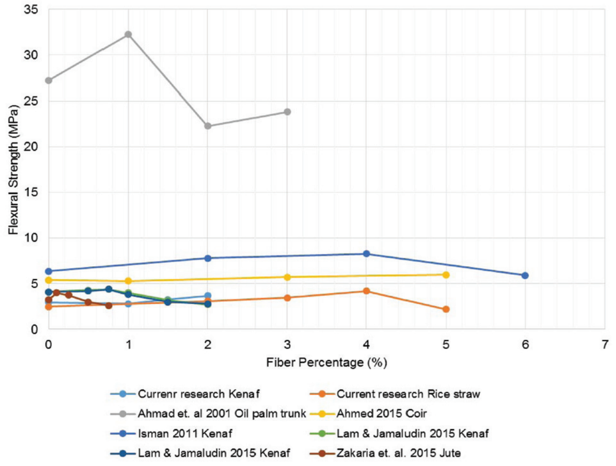

FIGURE 3. Flexural strength of KFRC and RSFRC compared to other NFRCS

RSFRC also shows that optimum value of fibre value at 4% produces the highest flexural strength. The volume percentages of all fibres that produce optimum flexural strength varies from 0.1% (jute) to 5% (coir). Oil palm trunk fibre RC show exceptionally high values of flexural strength due to the very exceptionally high tensile strength and bulk density of fibres (300 – 600 MPa and 1200 kg/m^2) (Ahmad et al. 2001) compared to other fibres, but with same trend, i.e. increase of fibre after certain limit, decrease the flexural strength.

Figure 4 shows the split tensile strengths of FRCs. It can be seen that the split tensile strength of RSFRC is optimum at 4% volume fraction of RS fibres. Other researches on hemp, coir and jute provide varied results depending on the water per cement ratio and other properties of the fibres such as elongation at failure and tensile strength (tensile strengths of hemp, jute and coir are at 690, 393-773, and 593 MPa, respectively).

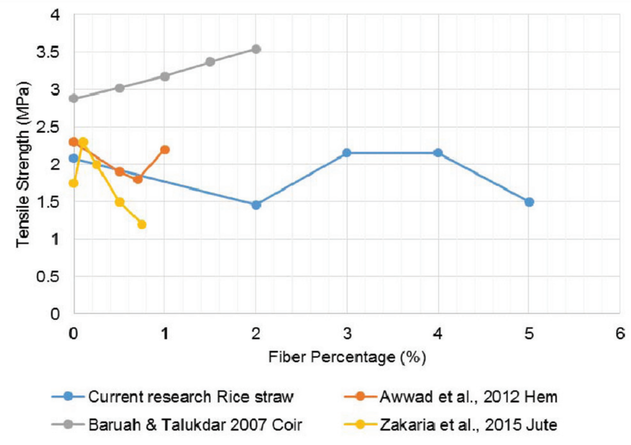

FIGURE 4. Tensile Strength of RSFRC compared to other NFRCs

Figures 5 and 6 show increasing trends of both energy absorption and impact resistance of concrete with natural fiber reinforcement. The trends show that, with increasing amount of fiber, increment of energy absorption and impact resistance were observed. Figure 5 shows that the energy absorption of RAFRC at 2% is superior compared to other fibres, except only coir. It also can be seen that RAFRC had exhibit better performance in resisting impact at 2% fibre content even though kenaf has superior properties compared to RA (Table 1) due to its higher ductility compared to kenaf.

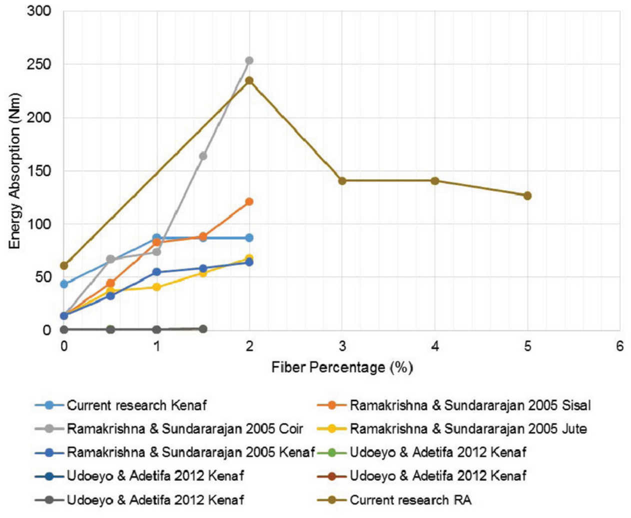

FIGURE 5. Energy absorption of KFRC compared to other NFRCs

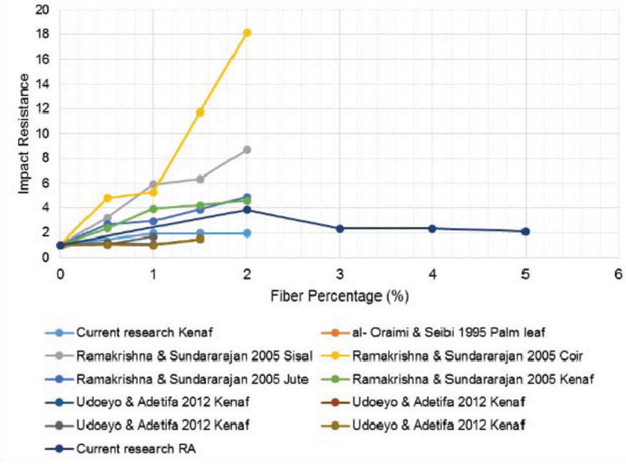

FIGURE 6. Impact resistance of KFRC compared to other NFRCs

CONCLUSION

The effect of kenaf and rice straw fibres addition, on compressive, flexural and split tensile strength of KFRC and RSFRC are similar as reported in earlier studies by various researchers, depending on the properties of each natural fibre. The compressive strength gradually decrease by the increasing volume of fibre (but at low fibre fractions) in the concrete for RSFRC but reverse to KFRC. The highest volume fraction of fibre recorded was 6% kenaf and the lowest was 0.1% jute, before compressive strength starts to decrease. For flexural and split tensile, a little variation in the trends, but most fibres increase the strengths with increasing amount at certain volume percentages. The most contribution of fibres in concrete is the impact and energy absorption, where addition of fibres have significantly increase the impact resistance and energy absorption of concretes at all values, being 2% as optimum and need more investigation as the trends are still increasing. The energy absorption of RAFRC at 2% is superior compared to other fibres, except only coir and exhibit better performance in resisting impact even though kenaf has superior properties compared to RA due to its higher ductility compared to kenaf. Further recommendation should be conducted on fibre treatment, so, low water absorption and high fibre-matrix bonding can be achieved, application of different admixtures to reduce voids in concrete and effect of fibre length to properties of concrete.

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