PERFORMANCE EVALUATION OF CRUMB RUBBER MORTAR REINFORCED WITH SYNTHETIC AND BANANA FIBERS

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ABSTRACT

The addition of crumb rubber as fine aggregate replacement in mortar have been known to decrease the mechanical properties of cement-based mortar. However, various methods have been investigated combat this problem such as the incorporation of various types of fiber like metallic, glass, polymer, carbon, mineral, and organic fibers in cement-based matrix. Generally, the objective of adding fibers in cement matrix is to improve the mechanical properties of its composite host through a crack-constraining scenario identified as the fiber-bridging phenomenon. The improvement in strength is dependent on various factors such as the matrix strength, fiber type, fiber modulus, fiber aspect ratio, fiber orientation, and aggregate size effects. In this study, synthetic polypropylene-polyethylene blend fibers are combined with natural banana fibers to improve the performance of crumb rubber mortar in compression, tension, and flexure. A total of 12 mix designs were developed with varying fiber combinations and rubber crumb replacement. Subsequently, a parametric study with chemical admixture was conducted at 3, 7, and 28 days to improve the flowability and the resultant mechanical properties of the HyFRM. It was observed that addition of fiber in the mortar matrix significantly decreases the workability as compared to the samples without fiber content. The reduction of compressive, tensile, and flexural strength was also observed to be directly proportional to the increase of crumb rubber content in the mortar matrix, and the HyFRM is observed to produce less compressive strength compared to mortar reinforced with single synthetic fiber. In tension, mortar samples C5F6 with 5% crumb rubber content and addition of 0.6% polypropylene-polyethylene blend fibers shows significant increase of 23.9% in split tensile strength compared to the control mortar. Significant decrease of flexural strength with an increase of crumb rubber content is also recorded for mortar samples at 3, 7, 28 days of curing.

ABSTRAK

PENILAIAN PRESTASI MORTAR SERBUK GETAH YANG DIPERKUAT DENGAN SERAT SINTETIK DAN PISANG

Penggunaan getah remah sebagai penggantian agregat halus dalam mortar telah diketahui dapat mengurangkan sifat mekanikal mortar. Walau bagaimanapun, pelbagai kaedah telah disiasat mengatasi masalah ini seperti penggabungan pelbagai jenis serat seperti logam, kaca, polimer, karbon, mineral, dan serat organik dalam matriks berasaskan simen. Secara amnya, objektif penambahan serat dalam matriks simen adalah untuk meningkatkan sifat mekanikal inang kompositnya melalui senario pengekangan retak yang dikenal pasti sebagai fenomena pengikat serat. Peningkatan kekuatan bergantung pada pelbagai faktor seperti kekuatan matriks, jenis serat, modulus serat, nisbah aspek serat, orientasi serat, dan kesan saiz agregat. Dalam kajian ini, serat campuran polipropilena-polietilena sintetik digabungkan dengan serat pisang semula jadi untuk meningkatkan prestasi mortar dalam mampatan, ketegangan, dan lenturan. Sebanyak 12 reka bentuk campuran dikembangkan dengan kombinasi serat yang berbeza-beza dan penggantian serbuk getah. Selepas itu, kajian parametrik dengan campuran kimia dilakukan pada 3, 7, dan 28 hari untuk meningkatkan kebolehaliran dan sifat mekanikal yang dihasilkan dari HyFRM. Telah diperhatikan bahawa penambahan serat dalam matriks mortar secara signifikan mengurangkan kebolehkerjaan berbanding dengan sampel tanpa kandungan serat. Pengurangan kekuatan mampatan, tegangan, dan lenturan juga diperhatikan berkadar langsung dengan peningkatan kandungan getah remah dalam matriks mortar, dan HyFRM diperhatikan menghasilkan kekuatan yang kurang mampatan berbanding mortar yang diperkuat dengan serat sintetik tunggal. Dalam ujain tegangan, sampel mortar C5F6 dengan kandungan serbuk getah 5% dan penambahan serat campuran polipropilena-polietilena 0.6% menunjukkan peningkatan ketara 23.9% dalam kekuatan tegangan pecah berbanding dengan mortar kawalan. Pengurangan ketara kekuatan lentur apabila kandungan serbuk getah ditingkatkan dapat dilihat terhadap sampel mortar pada 3, 7, dan 28 hari pengawetan di dalam air.

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V_f - Volume Fraction

LIST OF ABBREVIATIONS

FFF	-	Forta Ferro Fiber
BF	-	Banana Fiber
FRM	-	Fiber Reinforced Mortar
FRC	-	Fiber Reinforced Concrete
CR	-	Crumb Rubber
ASTM	-	American Society for Testing and Materials
W/C	-	Water Cement Ratio

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Cementitious materials are among the most desired and widely utilized materials in the building industry worldwide. This is mostly owing to its ease of handling, preparation, and tailoring into all intended forms and structural configurations at an early stage, such as before the curing process. According to research, the structures of cementitious materials may be broadly classified into four scales: cement hydration product, cement paste, mortar, and concrete. Although cementitious materials have several benefits, when exposed to pressures, they are prone to fracture development and subsequent propagation. The fundamental concern with cement-based materials is their brittleness, which is related to their rigidity. Such flaws will cause loss of their mechanical qualities, necessitating expensive maintenance or even rebuilding of such materials over a relatively short lifespan (Heo et al., 2021). For example, mortar is a common cementitious material used in a wide range of building applications, including wall construction, covering, ground finishing, crack filling, mending, and even decorating. The use of mortar in the production of these goods is primarily due to its various benefits, including rigidity, lightweight, forming ability, and volume stability, as well as a perfect finishing surface and quick installation. Hoang Quoc Vu et al. (2018), on the other hand, reported that mortar has poor bending and tensile resistance. Furthermore, it is possible to cause fracture and cracking in the manufacture of panels with high slenderness, especially in the production of covering panels and finishing plates.

There is a broad range of methods offered for addressing the brittleness problem of cement-based materials such as using silica fume and superplasticizers in cement-based materials to produce greater concrete strength. One of the emerging developments among these solutions is the incorporation of fiber in mortar and concrete, which provide a key contribution to the enhancement of strength properties. Fibers such as glass fiber, steel fiber, synthetic fiber, and natural fiber are known to be used to regulate the cracking, modify the behavior of the material after the matrix has fractured, and increase the strength qualities of cementitious materials. The table below displays the physical parameters of the commercial fibers.

Table 1: Physical Parameters of the Commercial Fibers

Type of fiber	Diameter (μm)	Specific Gravity (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Ultimate Elongation (%)
Metallic					
Steel	5-1000	7.85	2000-2600	195-201	0.5-5
Glass					
E glass	8/15	2.54	2000-4000	72	3.0-4.8
AR glass	8-20	2.70	1500-3700	80	2.5-3.6
Synthetic					
Acrylic (PAN)	5-17	1.18	200-1000	14.6-19.6	7.5-50.0
Aramid (e.g., Kevlar)	10-12	1.4-1.5	2000-3500	63-130	2.0-4.6
Nylon (polyamide)	20-25	1.16	965	5.17	20.0
Polyester (e.g., PET)	10-8	1.34-1.39	280-1200	10-18	10-50
Polyethylene (PE)	25-1000	0.96	80-600	5.0	12-100
Polyethylene (HPPE)	-	0.97	4100-3000	80-150	2.9-4.1
Polypropylene (PP)	10-200	0.90-0.91	310-760	3.5-4.9	6-15.0
Natural – organic					
Cellulose (wood)	15-125	1.50	300-2000	10-50	20
Coconut	100-400	1.12-1.15	120-200	19-25	10-25
Bamboo	50-400	1.50	350-50	33-40	-
Jute	-	1.02-1.04	250-350	26-32	1.5-1.9

Source: Domenico Brigante (2015)

Fibers have been used to strengthen materials that are substantially weaker in tension than compression since ancient times. Around 3500 years ago, sunbaked bricks reinforced with straw were used to build the high hill of Aqar Quf, an area near modern-day Baghdad (Bentur & Mindess, 2006). Asbestos cement was invented in the 1900s with the creation of the Hatschek method, becoming the first extensively used produced composite in modern times. Currently, diverse materials such as epoxies, plastics, and ceramics are typically reinforced with fibers. The chronology of the usage of fibers over the years is depicted in the image below.

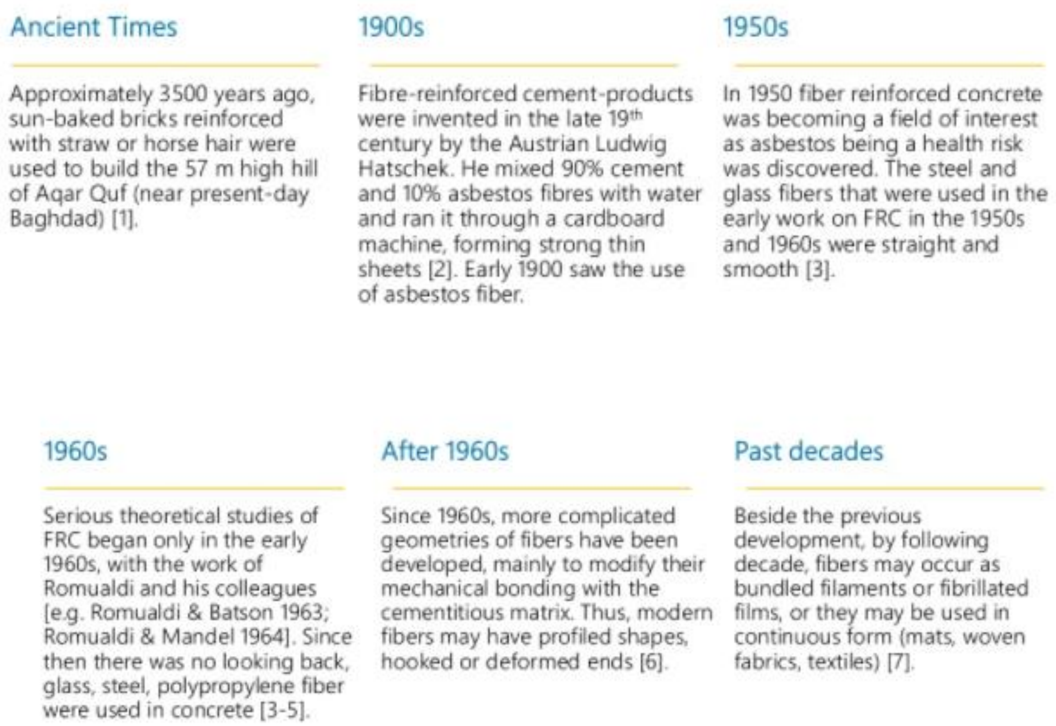

Figure 1: Timeline of the use of Fibers on Different Materials

Source: Bentur & Mindess (2006)

Mortar made of hydraulics cement containing fine aggregates and discontinuous discrete fiber is termed fiber-reinforced mortar (FRM) (Heo et. al., 2020). By employing fiber to strengthen mortar, it will boost tensile and bending. The presence of fibers in the mortar mixture has the purpose to resist the hydraulic shrinkage, typical of the mortar during the hardening process, thereby preventing the production of cracks and fissures on the surface of the plaster applied (Heo et al., 2021). In other words, insertion of short, randomly dispersed fibers would help to the increase ductility and toughness of cementitious materials. One of the most used parameters to evaluate the properties of FRM is the volume fraction of the incorporated fibers. Other parameters that might be employed include fiber count, fiber-specific surface area, and fiber spacing (Yurtseven, 2004). FRM characteristics and performance vary based on matrix properties as well as fiber material, fiber concentration, fiber shape, fiber orientation, and fiber distribution.

However, according to a study by Dawood et. al. (2011), the reinforcing effectiveness of a single fiber is restricted when compared to hybrid fibers with varying lengths, diameters, or aspect ratios. As a consequence, research on hybrid fiber reinforced cement composites has been conducted, which may enhance the effects that single fibers cannot do by mixing two or more kinds of fibers with different material qualities in an appropriate ratio. Two or more types of fibers are strategically blended to generate a composite that benefits from each component fiber while also demonstrating a synergetic response in hybrid fiber reinforced mortar. While reinforcement with a single type of fiber may improve properties to a limited extent, hybridization with two or more different types of fibers incorporated in a common cement matrix can provide more appealing engineering properties because the presence of the first fiber allows for more efficient utilization of the properties of the other fiber.