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Flexural Behavior of Reinforced Concrete Beams Using Hybrid Fiber and Recycled Industrial Waste

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ABSTRACT

The effect of using mixture of rubberized concrete containing polypropylene (PP) and Polyvinyl alcohol fiber (PVA) to improve the flexural behavior of reinforced concrete beams is the main aim of this work. This study consists of Performing the laboratory experiments to study the extent of improving the Flexural behavior of concrete beams as a result of adding a mixture of rubber concrete, polypropylene (PP) and polyvinyl alcohol fiber (PVA) in different proportions and investigating the mechanical properties of the produced beams. The bonding efficiency between crumb rubber and concrete was analyzed through testing the compressive strength and flexural behavior of beams with 20% crumb rubber (CR) contents and different types of hybrid fiber additives to the mixtures used to enhance the beams' properties. The results indicated that the compressive strength of the crumb rubber (CR) content of 20% with zero fiber was 20.5 MPa.The optimum compressive strength of beams are obtained with crumb rubber content of 20% and (0.5% PP+0.5%PVA).It was found that the beams had ultimate strength, ranging from 87.4 to 84.64 KN . The ultimate strength of rubberized beams with hybrid fiber (PP+PVA) was investigated and it was found that the produced beams have an acceptable resistance in comparison with the recycled rubber concrete without fiber reinforced of the beams.

KEYWORDS: Crumb rubber; Fiber; Polyvinyl alcohol; Polypropylene; Flexural behavior.

سلوك الانحناء للكمرات الخرسانية المسلحة المصنعة بأستخدام الألياف والمخلفات الصناعية المعاد تدويرها

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الملخص

تعد المخلفات الصناعية من المشكلات البيئية التى تعانى منها مناطق كثيرة فى العالم . واستجابة للمتطلبات البيئية والاقتصادية فقد اتجهت الابحاث العلمية إلى تدوير المخلفات الصناعية لدراسة امكانية استخدامها كركام فى الاعمال الأنشائية. ولذلك فقد اهتمت هذة الدراسة بمدى امكانية استخدام المخلفات الصناعية فى انتاج خرسانه تصلح للعناصر الأنشائية .

والهدف الرئيسى من هذا البحث هو دراسة تأثير استخدام خليط من الخرسانه المطاطية بنسبة ٢٠٪ ونسب مختلفة من ألياف البولى فينيل الكحول (PVA) وألياف البولى بروبلين (PP) لتحسين السلوك الأنشائي للكمرات الخرسانية المسلحة .

تتكون هذه الدراسة من إجراء التجارب المعملية حيث تم وضع برنامج عملى لصب أربعة خلطات لتنفيذ أربعة كمرات مسلحة بسيطة الارتكاز لدراسة سلوكها فى الانحناء.

الكلمات المفتاحية : الخرسانه المطاطية، سلوك الانحناء، البولى فينيل الكحول ، البولى بروبلين ، ألياف.

1. INTRODUCTION

There is a worldwide problem of waste tires which can cause significant health and environmental problems [1]; waste tire rubber can therefore be recycled into civil engineering materials, particularly in Portland cement concrete to reduce the environmental effects [2]. There have been significant advances in the use of waste tires as aggregates in concrete in the past few years. Some properties that can be improved by adding rubber aggregates to plain concrete , such as energy absorption, freeze-thaw resistance, and toughness, have been studied extensively in recent years[3, 4]. However, the low stiffness of rubber debris causes a decrease of compressive strength as compared with plain concrete. The elastic rubber should produce larger deformations than cement paste beneath the compressive load and boost up the initiation of cracks [2, 5]. Tire chips or crumb rubber debris have been decided to partly replace the soft or coarse aggregates, respectively. The consequences confirmed that the compressive power of the coarse mixture had a 30% decrease in comparison with the soft mixture.

Tests showed that when 15% of the fine aggregates were replaced with crumb rubber, the compressive strength was reduced by about 10%. They additionally determined that the compressive power of rubberized concrete might be decreased with the aid of introducing greater rubber aggregates. Khatib and Bayomy [6]. In the presence of more than 40% replacement fraction of fine aggregates, the fresh properties, such as slump, approached zero, and the mixture was not able to attain good workability. It has been shown that adding a high percentage of rubber aggregate to plain concrete will reduce its compressive strength [5], but it will improve its toughness and impact resistance [7, 8]. In general, the recycling of rubber tires into Portland cement concrete can lessen environmental dangers and keep physical materials. Waste tire rubber can be used to replace fine aggregates in traditional concrete to some performances improved by rubber particles. As a result of adding scrap tire rubbers, the strength was reduced [9]. As a result, fiber-reinforced concrete has the benefits of controlling cracking , improving flexural behavior , and reducing shrinkage during drying compared to plain concrete [10, 11]. Although crumb rubber CR decreases mechanical properties significantly , a successful mixture of CR with hybrid fibers was obtained [12] .

Therefore, it is recommended to use rubberized concrete in lightweight construction applications and to avoid its use in heavy structures that require high compressive strength [13].There have been many uses for fiber-reinforced concrete, including architectural panels, concrete slabs, precast concrete slabs, shot crete, ultra-high-performance concrete, concrete pavement and slab on grade applications and others [14, 15,16]. However, the utilize of these materials in concrete is currently lower than expected due to the lack of information and results on this application, especially long-term observations. Therefore, this thesis reviews the potential of recycling some industrial wastes as construction materials in concrete industry. In particular, the feasibility of recycled rubber concrete and reinforced with fiber was checked in terms of mechanical performance.

2. MATERIALS AND METHODS

2.1. Raw materials

The materials used in this study included Tire-rubber particles have been provide by the Marso Tire Company in 10th Ramadan city in Egypt. Water used in all study was normal tap water. Natural siliceous sand with a fineness modulus equal to 2.91and a specific gravity of 2.6 was used in the current study. The crushed dolomite was used in preparing concrete specimens was clean and free of silt and clay. Sulfate-resisting pozzolanic cement [CEM IV /A (P) (42.5 N- SR)] is an excellent building material due to the excellent bonding properties that give strength to structural elements. Within this study, two different types of fiber materials; polypropylene fiber (PP) and polyvinyl alcohol fiber (PVA), have been used. Silica fume used in this study was supplied by a certain Silica fume supplier in Egypt. According to the product data sheet, the used Silica fume has a specific gravity of 2.2. In addition, a high-range water-reducing admixture (Super Plasticizer) was used to produce concrete with a high workability. There are three types of steel bars used in this study. Steel bars of 12 mm and 10 mm diameter .The stirrups used were mild steel bars of 8mm.

2.2. Objective of the experimental program

The main objective of this study is to investigate behavior of rubberized concrete. The various specific objectives are:

- Studying the flexural behavior and compressive strength of rubberized concrete.
- Effect of using mixture of rubberized concrete and containing polypropylene (PP) and Polyvinyl alcohol fiber (PVA) to improve the flexural behavior of reinforced concrete beams.
- Investigate mechanical performance of rubberized concrete beams.

2.3. Details of test specimens

The experimental program was conducted on Four Mixtures. All Mixtures with three cubes plus the one beam each end as shown as detailed at **Table 1.**

Table 1: Details of test specimens

Mixture	Volume of Crumb Rubber	Volume of Fiber	Cube (mm)	Reinforced Concrete Beams (mm)		
				b (mm)	t (mm)	L (mm)
Mix 1 control	0	0	150*150*150	120	250	2000
Mix 2	20%	0	150*150*150	120	250	2000
Mix 3	20%	0.75% PVA ,0.75% PP	150*150*150	120	250	2000
Mix 4	20%	0.5% PVA ,0.5% PP	150*150*150	120	250	2000

2.4. Casting and curing mix

Benha University's laboratory was the site of the concrete mixture preparation. Rubber was dry mixed in a container with cement, sand using mixer (in case of mortar containing rubber and fiber). After that water was added to the dry mixture and mixed. The mortar was placed in molds and compacted. Wood forms were used in casting the beams. The curing phase, which lasted for 28 days, began after the beams and cubes were taken out of the formwork. The steps involved in getting a specimen ready are shown in **Fig. 1**

Fig1: Mixing, casting, and curing of specimens

2.5. Experimental test

- **Compressive strength**

As shown in **Fig. 2** test the cubes for compressive strength

Fig. 2: Compressive strength test

- **Setup of tested beams**

Four beams were tested to study their behavior under flexural loadings as shown in **Fig. 3** and **Fig. 4**, provide details of beams.

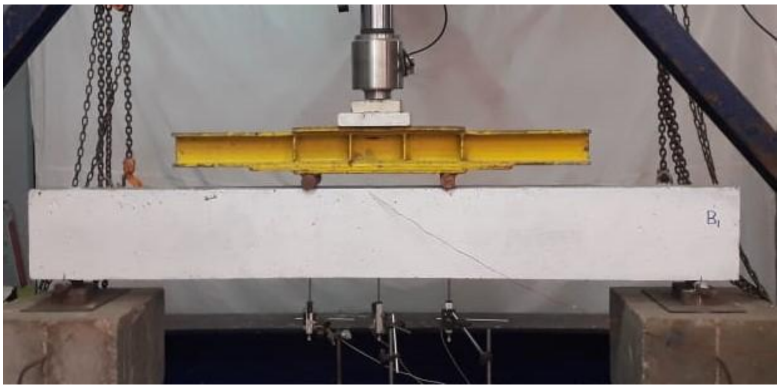

Fig. 3: Test setup

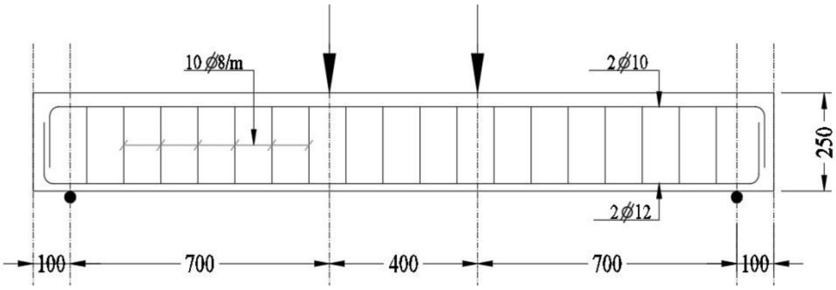

Fig. 4: Details of beams

3. RESULTS AND DISCUSSION

The compressive strength decreased when rubber fibers were used. The low strength and elasticity modulus of rubber aggregate and the weak bond between the crumb rubbers and other materials in the mixture (due to hydrophobic properties of crumb rubbers) may lead to low strength of Rubberized Concrete. Overall, the effects of combining PVA and PP in Rubberized Concrete mixes result in materials with superior mechanical properties. These enhanced properties include increased flexural properties of rubberized concrete. Such improvements are crucial for the development of durable and resilient concrete structures capable of withstanding the challenges of modern construction environments. The properties of mixtures are shown in **Table. 2**, **Fig. 5**.and **Fig.6**. **Fig. 7 to 10** display the cracking patterns for each beam specimen. For all beams, the first crack appeared almost in the middle of the beam.

Table 2: Results of Mixes

Mixture	Mix 1 control	Mix 2	Mix 3	Mix 4
Compressive Strength (N/mm^2)	49.7	20.5	12	13.5
First Crack Load Pcr (KN)	20	15	20	20
Ultimate Load Pu (KN)	94.52	82.26	84.64	87.4

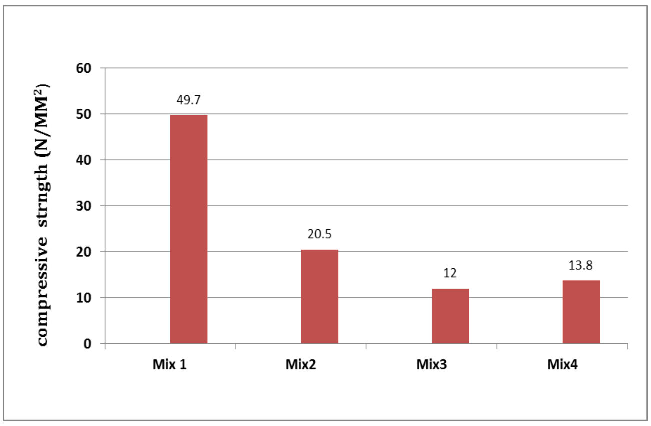

Fig. 5: Compressive Strength

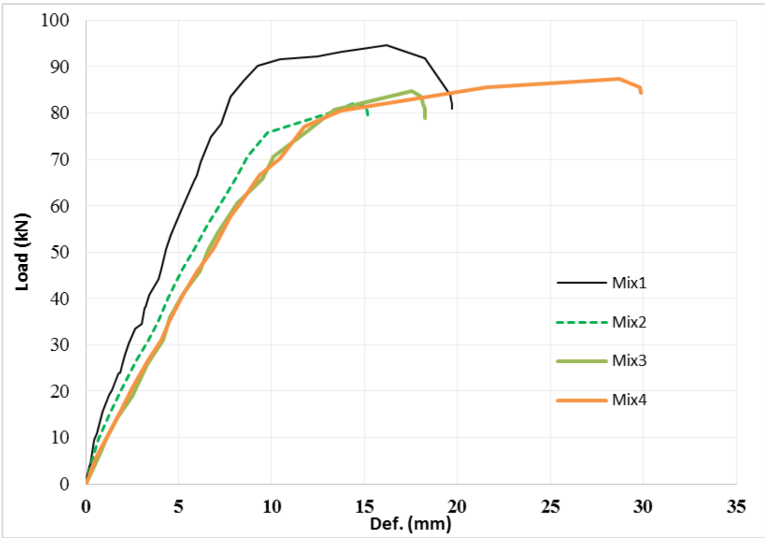

Fig. 6: Load-Deflection Relationship of Mixes

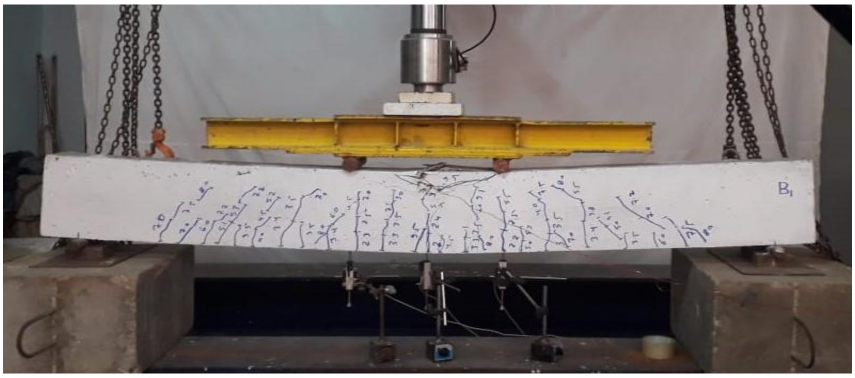

Fig. 7: Cracks patterns of Mix1 specimen.

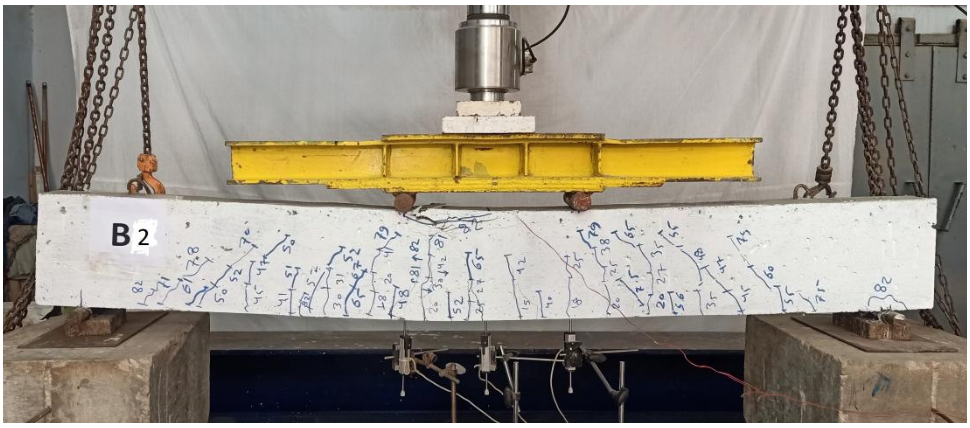

Fig. 8: Cracks patterns of Mix2 specimen.

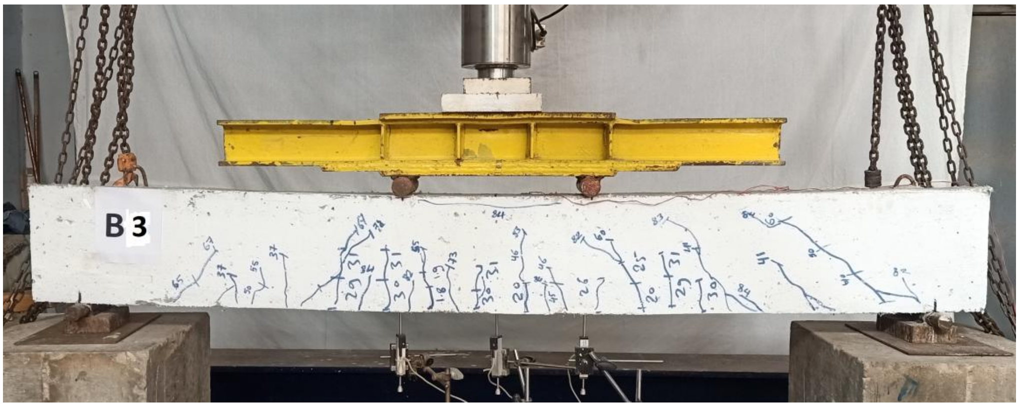

Fig. 9: Cracks patterns of Mix3 specimen.

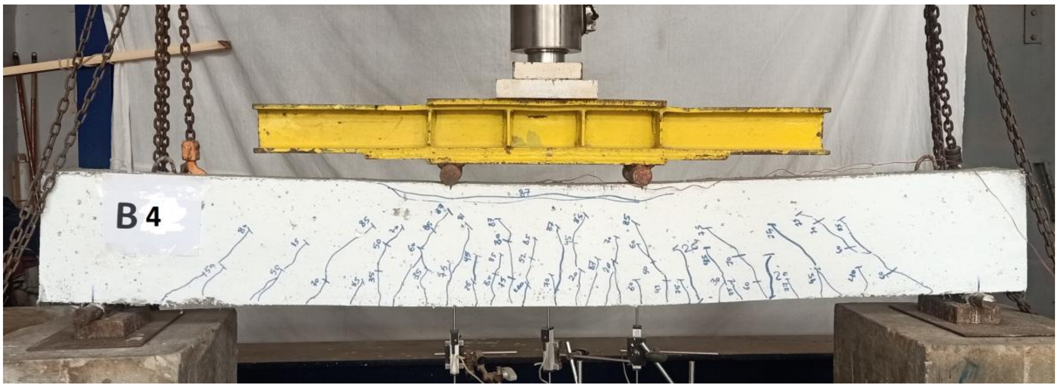

Fig. 10: Cracks patterns of Mix4 specimen.

CONCLUSIONS

The investigation into the effects of crumb rubber, Polyvinyl Alcohol (PVA) and polypropylene (PP) fibers on the compressive and flexural behavior of reinforced concrete beams valuable insights into the enhancement of concrete performance. Through a comprehensive review of existing literature and research findings, several key conclusions.

The addition of rubber aggregate to concrete creates a new type of mixture called rubberized concrete, which combines the environmental benefits of rubber concrete with the industrial benefits of concrete.

According to results, the compressive strength of reinforced concrete decreased by 41% after adding 20% of rubber aggregate.

Mix 3 and Mix 4 reinforced with (PVA) and (PP) fibers can improve post-cracking properties with up to 1.33 times better first crack strength compared to Mix 2.

Adding polyvinyl alcohol (PVA) and polypropylene (PP) fibers to rubberized concrete enhances crack resistance and flexural behavior by forming a strong reinforcement network while offering environmental and economic benefits.

REFERENCES

[1] X. Shu, B. Huang., 2014. Recycling of waste tire rubber in asphalt and portland cement concrete: an overview, Constr. Build. Mater. 67, 217–224.

[2] G. Li et al.,2004.Development of waste tire modified concrete, Cem. Concr. Res. 34 (12) , 2283–2289.

[3] T. Naik, S.,1991.Singh, Utilization of discarded tires as construction materials for transportation facilities. in 70th Annual Meeting of Transportation Research Board.

[4] N. Segre, I. Joekes.,2000. Use of tire rubber particles as addition to cement paste, Cem.Concr. Res. 30 (9) , 1421–1425.

[5] E. Ganjian, M. Khorami, A.A. Maghsoudi.,2009. Scrap-tyre-rubber replacement for aggregate and filler in concrete, Constr. Build. Mater. 23 (5) , 1828–1836.

[6] Z.K. Khatib, F.M. Bayomy.,1999. Rubberized Portland cement concrete, J. Mater. Civ. Eng. 11 (3), 206–213.

[7] I.B. Topcu.,1995. The properties of rubberized concretes, Cem. Concr. Res. 25 (2) , 304 – 310.

[8] M.M. Reda Taha et al.,2008. Mechanical, fracture, and microstructural investigations of rubber concrete, J. Mater. Civ. Eng. 20 (10), 640–649.

[9] G. Li et al.,2004. Waste tire fiber modified concrete, Compos. B Eng. 35 (4), 305–312.

[10] S. Liu et al.,2018. Flexural response of basalt textile reinforced concrete with pretension and short fibers under low-velocity impact loads, Constr. Build. Mater.169 , 859–876.

[11] Y. Ou, D. Zhu.,2015. Tensile behavior of glass fiber reinforced composite at different strain rates and temperatures, Constr. Build. Mater. 96, 648–656.

[12] Emad A.H. Alwesabi et al.,2020. Experimental investigation on mechanical properties of plain and rubberised concretes with steel–polypropylene hybrid fibre, Construction and Building Materials 233 , 117194.
[13] Mohamed Fouad A. Abdu et al.,2021. Behavior of concrete containing waste rubber tire as partial replacement of coarse aggregate,(NTC) 12-16 March,Sharm El-sheikh, Egypt.
[14] N. Banthia.,1994. Fiber Reinforced Concrete, ACI SP-142ACI, Detroit, MI, pp. 91–119.
[15] J. Zhang, Y. Zhao.,2017. The mechanical properties and microstructure of ultra-highperformance concrete containing various supplementary cementitious materials, J. Sustain. Cem. Based Mater. 6 (4) , 254–266.
[16] Abdulaziz Alsaif et al.,2022.Strength, durability and shrinkage behaviours of steel fiber reinforced rubberized concrete, Construction and Building Materials 345, 128295.