An Experimental Investigation on Ferrocemet: Comparative Study.

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ABSTRACT

Ferrocement is a form of reinforced concrete made up of closely spaced layers of wire mesh and reinforced bars embedded in cement mortar. Generally the mortar consists cement and sand in a ratio of 1:2 and galvanised steel is used to avoid corrosion. This is an advanced and versatile construction technology that extensively used worldwide. This is adopted for its unique behaviour such as higher degree of ductility, high tensile strength, greater stiffness, high resisting capacity to crack formation and cost effective solution that it can replace conventional RRC construction in many ways. Generally thickness of components are less than 25 mm. Structures made by ferrocement gains strength by its shape not by size. Critical shapes can be constructed by this technology which may not be possible in RCC construction work. Many researchers have already been conducted many tests to investigate the behaviours and characteristics of ferrocement and its elements. This construction technology is mostly adopted in unreachable places like hilly areas where mobilization of construction materials is big challenge. The main aim of this experimental investigation is to find out the mechanical behaviours such as compressive strength and flexural strength of ferrocement in which cement is partially replaced with PVC (Poly Vinyl Chloride) waste. Number of rectangular slab were tested having different layers of wire mesh varied from single, double and triple layers. The specimens were cured for 3, 7, 14 and 28 days in an ambient water tank. According to the test results, graphs are plotted and compared with conventional ferrocement made by normal cement mortar.

Key words: Ferrocement; GGBS; PVC waste; compressive strength; flexural strength.

1. Introduction

Plastic has become one of the most used substances by humans due to its easy availability. Large quantities of post-consumer waste plastic have become a global issue as it is affecting the health of entire earth including mankind, wildlife and aquatic life. Tons of postconsumer waste plastic are dumped into ocean or disposed of by land filling. It is not dissolved in either soil or marine water. Disposal of waste in such a manner results in reduction in soil fertility, reduction in water percolation, polluting air by emission of toxic gases, health hazard to animals and birds consuming the wastes, polluting ground water due to leaching of chemicals from these waste products. Researchers finding different ways to use these waste plastics in a productive manner. Consumption of Cement based composites is huge in quantity. Here in this paper PVC (Poly Vinyl Chloride) waste powder is replaced partially in cement composite. This would be the safe disposal method also improves the concrete properties like compressive strength, chemical resistance, drying shrinkage and creep in long and short term basis.

In 1840 ferrocement is originated in France and the Netherlands, this is also the origin of reinforced concrete. It has wide range of uses including prefabricated building components and sculptures. It is an excellent construction material having significant qualities like toughness, impact resistance and crack control. Thin and light weight concrete structures are constructed achieving high strength due to close spacing and uniform dispersion of reinforcement within the material. Many experimental investigations expresses the physical and mechanical properties of this material and number of test data are available for design and construction. Conventional ferrocement construction procedures are laboured intensive and less efficient. If mechanical method for plastering is adopted then it would be more convenient and cost effective. There are many advantages of this construction method as follows:

a) No formwork, scaffolding, bricks, stones, or stone aggregates are required hence the cost of construction is reduced.
b) Foundation design becomes lighter and cheaper, less differential settlement occurs.
c) Plastering cost and time is saved
d) More carpet area in buildings can be accessed.
e) Critical designs can be constructed

   Structure has good earthquake resistance. This can undergo large deformation before collapse.

2. Materials

The entire thing required to be done for achieving the objective of this experiment are described below. From the collection of the replacement a material that is PVC waste

(Polyvinyl Chloride) along with the preparation of testing of rectangular slab and all experimental data for the experiment PVC waste are given below.

2.1 Cement

Portland pozzolana cement of Fly ash based from a single batch was used for the entire work and special care was taken so that the cement doesn't contact with ambient air. All the physical and chemical parameters of the PPC cement was tested before its use according to IS: 1489-2015(Part 1). The physical and chemical properties are given in Table-1 and Table-2 respectively.

Table 1: Physical properties of PPC (Portland Pozzolana cement)

Physical properties	**Values**	
Standard Consistency (%)	33	
Specific Gravity	2.90	
Initial setting time (minutes)	30 (Min)	
Final setting time (minutes)	600 (Max)	
Fineness (m^2/kg)	300	
Soundness (mm)	10 (Max)	
Compressive Strength (MPa)	3 days	22.2
	7 days	28.5
	28 days	33.6
% of Fly Ash addition	34.8 (15.0 (Min), 35.0 (Max))	

Table 2: Chemical properties of PPC (Portland Pozzolana cement)

Chemical Properties (% by mass)	**Values**
Insoluble Residue	32.17
Magnesia	1.70 (6.00 (Max))
Sulphuric Anhydride	1.98 (3.50 (Max))
Loss on Ignition	1.58 (5.00 (Max))
Total Chloride	0.010 (0.10 (Max))

2.2 Fine Aggregate

The river sand which is passing through 4.75 mm sieve and retained on 600 µm sieve, conforming to Zone II as per IS 383-2016 was used as fine aggregate in the present experiment of ferrocement. The sand is free from clay, silt and organic impurities. The properties of fine aggregate were examined according to IS: 2386-1963 before its use. The properties fine aggregates are given in Table-3.

Table 3: Physical properties of Fine aggregate (River sand)

Physical properties	**Values**
Fineness Modulus	2.5
Water Absorption	0.8%
Specific Gravity	2.51
Bulk Density	1610kg/m3

2.3 Water

Fresh portable or non-portable water which is free from organic matter and oil is permitted to mixing of cement and sand for preparation of mortar. Parameters, specially pH value should be tested before its use.

2.4 Wire Mesh

There are many types of wire mesh introduced in construction work. In this research work Square welded wire mesh were used as the reinforcement in ferrocement work.

2.5 PVC Waste

Thermo plastic resins PVC waste are used in this research work which have number of versatile properties including durability, light weight and low cost. Hence it replace with cement and examine the compressive and flexural strength of mortar wising different layers of wire mesh. Properties of PVC are given in Table-4.

Table 4: Properties of PVC

Physical properties	**Values**
Density (g/cm^3)	1.3-1.45
Resistivity(Ω)	10^{16}
Yield strength (psi)	4500-8700
Flexural strength (psi)	490,000
Compressive strength (psi)	10,500
Thermal conductivity (W/m.K)	0.14-0.28
Coefficient of thermal expansion	9.500

3. Methodology

3.1 Mix proportion and specimen preparation

In order to investigate the compressive strength and flexural strength of PVC waste ferrocement, number of specimen were tested having different proportion of PVC waste replacement with cement. Also different layers of wire mesh are introduced in ferrocement rectangular slabs. The replacements of PVC waste with cement of 0.2%, 0.4% and 0.6%. The mortar composition was 1:2 (Cement: Fine aggregate). The water content is 0.45, taken for the entire experiment.

For the preparation of rectangular slab having dimension 970mm X 300mm X 35mm, materials are taken according to the proportion and gently mix for 4-5 minutes. During the preparation of mixture, designed amount of water were added and specimen were then prepared. For the placement of wire mesh, firstly a thin layer of mortar placed and spread by a trowel. Then a wire mesh was placed on it, then again a thin layer of mortar was placed on the reinforcement cage. A vibrator was used for proper spread of mortar mix in all direction. Likewise three layer wire mesh mortar specimen was prepared. After preparation of specimen, it was allowed for 24 hours for open air to set. The specimens were then de-moulded after 24 h and immersed in normal water for curing until the test age.

3.2 Test Program

The main objective of the study was to determine the compressive and flexural strength of PVC waste replaced ferrocement. The compressive strength and flexural strength was measure using UTM (Universal Testing Machine) with one point load. Different proportioned mixes with different layers of wire mesh were tested. Performance was measured for 3, 7, 14 and 28 days of curing. Three specimens were tested for each mix and for each curing age, the mean values were reported.

4. Results and Discussions

Table 5: Compressive strength results according to the replacement of PVC waste with curing time.

		PVC waste replacement with cement (%)			
Days	LAYERS	0	0.2	0.4	0.6
3	1	26.2	26.15	26.42	26.14
	2	26.1	26.36	26.47	26.22
	3	27.23	27.47	27.55	27.47
7	1	27.57	27.91	27.13	27.76
	2	27.76	28.1	28.32	27.96
	3	28.06	28.43	28.77	28.15
14	1	27.94	28.32	28.61	28.25
	2	28.21	28.66	28.97	28.56
	3	28.55	28.97	29.33	29.07
28	1	28.3	28.76	29.1	28.55
	2	28.61	29.13	29.46	28.92
	3	29.12	29.71	30.13	29.44

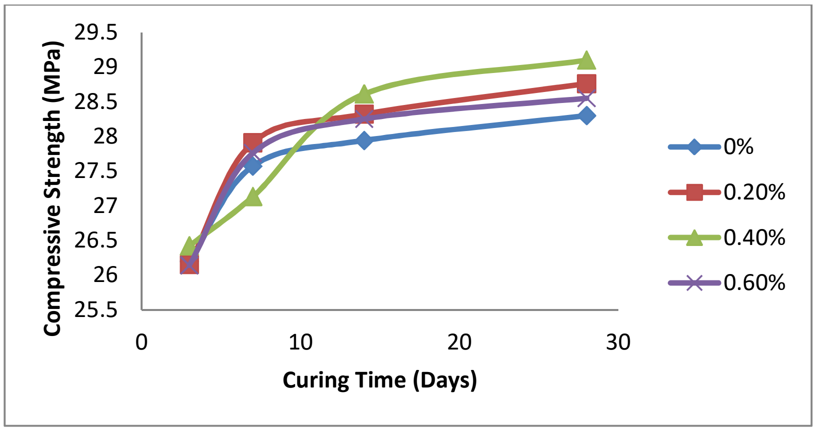

Figure 1: Compressive strength vs. curing time in single layer wire mesh

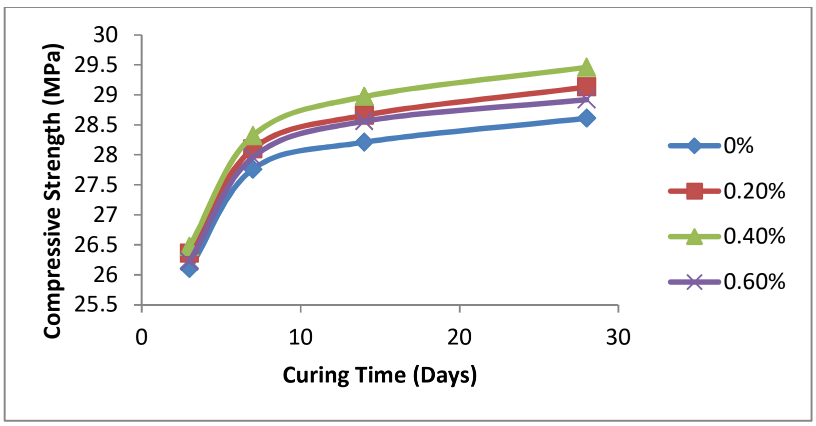

Figure 2: Compressive strength vs. curing time in single layer wire mesh

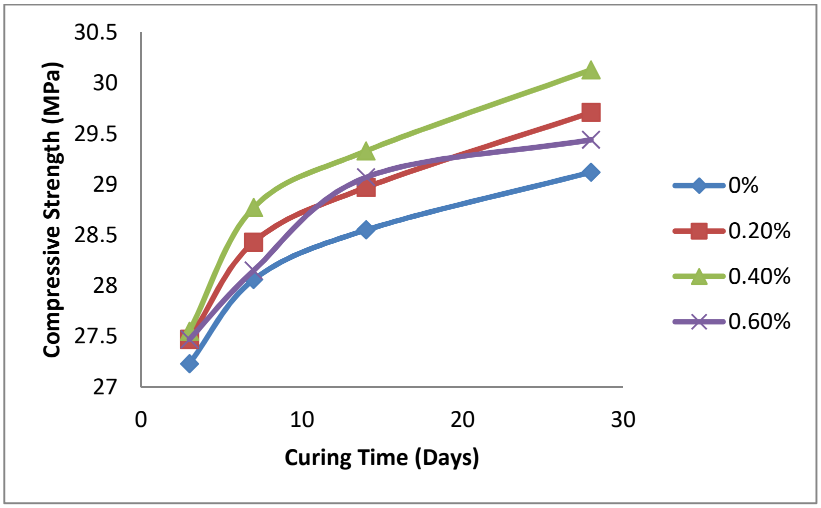

Figure 3: Compressive strength vs. curing time in single layer wire mesh

Figure 1 depicts the details about, how compressive strength is varying with curing time, percentage of replacement in a single layer ferrocement slab. The tests were conducted in 3, 7, 14 and 28 days of curing interval respectively, which is given in Table-5. In first 3 days the compressive strength gain by slabs was between 26 to 26.5MPa. But after 7 days it was increased by 5%, 7% after 14 days and 9% after 28 days. It was shown that the compressive strength was maximum at 28 days of curing with 0.4% of PVC waste replacement. In behalf of replacement percentage, it was observed that when the percentage increased also compressive strength was increase. But after 0.4% PVC waste replace, compressive strength was gradually decreased. The maximum compressive strength was attains 29.1MPa at 0.4% of waste replacement. At 7 days of curing, 0.4% replacement slab was gain minimum amount of compressive strength as compare to all other replacement percentage of PVC waste. So 0.2% of waste replacement is the good quantity for constantly gaining strength for ferrocement structure construction accordance with others. Whereas Figure 2 depicts the details about double layer based wire meshed ferrocement slab with 0.2%, 0.4% and 0.6% of PVC waste replacement. In this figure the minimum strength is obtains at 0.2% of replacement at high at 0.4% replacement with constant increasing trend. The minimum compressive strength is 26.1MPa, whereas maximum is obtained at 28 days of curing with 0.6% replacement i.e.28.9MPa. Figure 3 shows the variation of compressive strength with curing time for normal and PVC waste replacement ferrocement. As shown, compressive strength was increased with increase in curing time. In first 3 days of curing, ferrocement gained 7 to 8% of compressive strength. The rate of increase of strength is 7 to 10%. The minimum strength was 27.47MPa at 0.2% of replacement, whereas the maximum strength was obtained at 28 days of curing with 0.4% replacement.

Table 6: Flexural strength results according to the replacement of PVC waste with curing time.

		PVC waste replacement with cement (%)			
Days	LAYERS	0	0.2	0.4	0.6
3	1	0.98	1.16	1.41	1.13
	2	1.1	1.34	1.49	1.21
	3	1.21	1.49	1.54	1.46
7	1	1.57	1.9	2.11	1.77
	2	1.77	2.11	2.31	1.95
	3	2.06	2.42	2.75	2.16
14	1	1.93	2.31	2.62	2.24
	2	2.24	2.62	2.98	2.57
	3	2.57	2.98	3.34	3.03
28	1	2.31	2.75	3.11	2.57
	2	2.62	3.11	3.47	2.93
	3	3.11	3.7	4.11	3.45

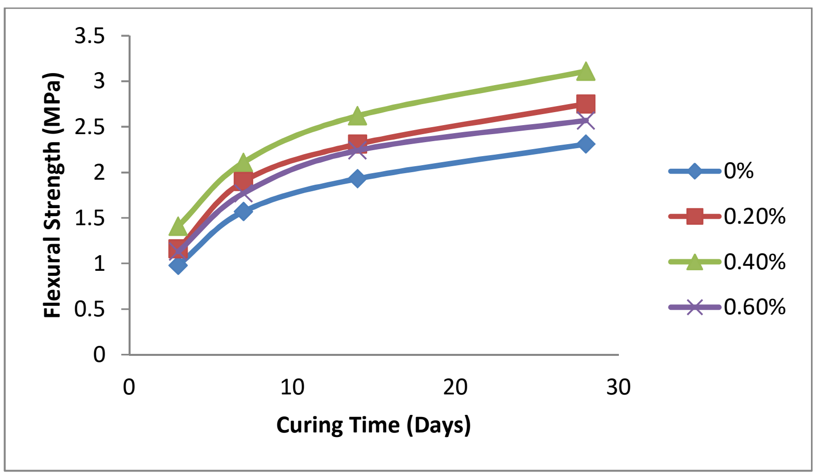

Figure 4: Flexural strength vs. curing time in single layer wire mesh

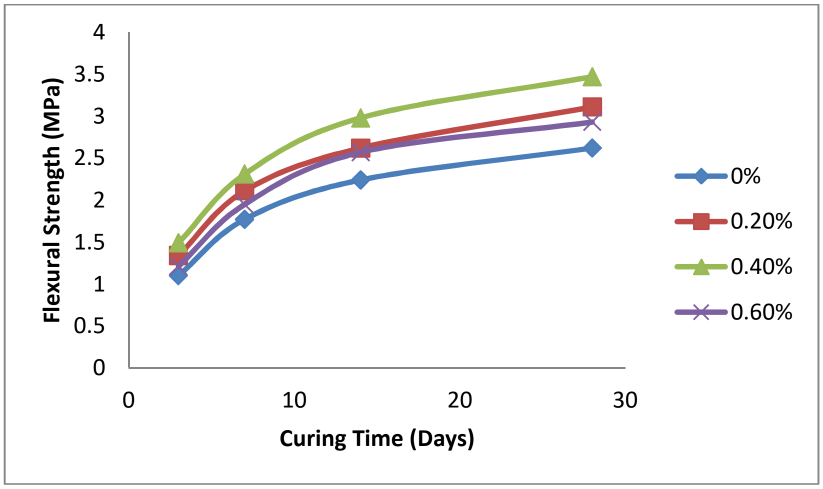

Figure 5: Flexural strength vs. curing time in double layer wire mesh

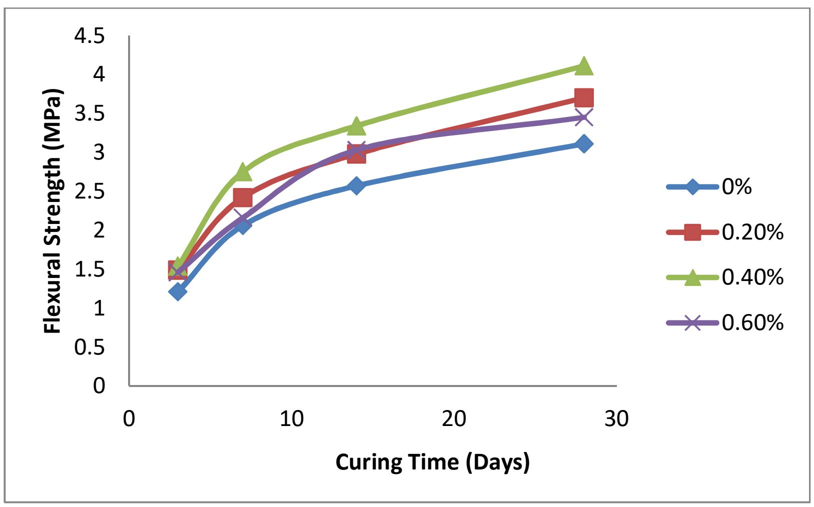

Figure 6: Flexural strength vs. curing time in triple layer wire mesh

Figure 4 depicts the details about the flexural strength varying with curing time, percentage of replacement in a single layer ferrocement slab, where the cast slabs were cured in water for 3, 7, 14 and 28 days respectively which is given in Table-6. In first 3 days flexural strength increase from 0.98 to 1.41MPa. For PVC waste replacement it was increase between 49% and 63% of its 7days of curing. After 14 days it was increased between 21 to26% and 15 to 19% after 28 days of curing. It was shown that the flexural strength increasing rate was maximum at first 7 days of curing and after that the increasing rate was gradually decreased. But it was observed that when the replacement percentage increased also flexural strength was increase. But after 0.4% PVC waste replace, flexural strength was gradually decreased. The highest strength was attains for 0.2% and 0.4% replacement. At 7 days of curing, 0.4% replacement slab was gain minimum amount of flexural strength as compare to all other replacement percentage of PVC waste. So 0.4% of waste replacement is the good quantity for constantly gaining strength for ferrocement structure construction accordance with others. Whereas Figure 2 depicts the details about double layer based wire meshed ferrocement slab with 0.2%, 0.4% and 0.6% of PVC waste replacement. In this figure the minimum flexural strength is obtains at 0.6% of replacement at high at 0.4% replacement with constant increasing trend. The minimum flexural strength is 1.21MPa, whereas maximum is obtained at 28 days of curing with 0.4% replacement i.e.3.47MPa. For the waste replacement it was increase between 55% and 61% of its 7days of curing. After 14 days it was increased between 24 to 45% and 14 to 18.5% after 28 days of curing. It was shown that the flexural strength increasing rate was maximum at first 7 and 14 days of curing and after that the increasing rate was gradually decrease. Figure 3 shows the variation of flexural strength with PVC waste replacement for three layer based ferrocement. As shown, flexural strength was increased with increase in curing time. In first 3 days of curing, ferrocement gained 7 to 8% of flexural strength. The minimum strength was obtained at 3 days of curing with 0.6% replacement i.e. 1.46MPa whereas the highest strength was 4.11MPa at 0.4% at 28 days of curing. For the waste replacement it was increase between 47% and 78% of its 7days of curing which is the highest increase rate for the entire flexural strength investigation. After 14 days it was increased between 21 to 40% and 13 to 24% after 28 days of curing which gives a downward trend of increasing rate.

In above result analysis it was clear that, compressive and flexural strength were increased with increase in curing duration whereas the strength was decrease after 0.2 and 0.4% of replacement. It also observed that, the strength was increased with increase in numbers of wire mesh layer. The triple layer slabs are showing the maximum strength and the double layer slabs are showing minimum as compared to the single layer slabs.

5. Conclusions

The results of this study have led to the following conclusions:

1. The rate of increase of compressive and flexural strength is higher than the normal mortar cement casting. The strength is increased with increase in curing period for entire casting of PVC waste ferrocement. 0.2% and 0.4% of replacement gives the advantage for long term rate of strength gain.
2. At all curing period, flexural strength of ferrocement with PVC waste up to 15 to 20% higher than normal ferrocement. As the maximum strength found at 0.4% PVC waste

replacement, which is the optimum replacement for both compressive and flexural strength.

3. With increase in number of layers, flexural and compressive strength were increased for all PVC waste replacement. In general, the percentage increase rate is similar for normal and PVC waste ferrocement with increase in mesh layer.
4. For structural application of ferrocement, fabrication is a key factor and deflection is a major design limitation. Grouped mesh reinforcement and skeletal steel along with fibre reinforcement can increase stiffness of the composite and substantially reduce deflection at all stages of loading.
5. The type of shape geometry of fibre had a significant influence on steady cracking stage. With fibres the load carrying capacity could be as high as 60-80 % compared to about 25 % for slabs without fibres.
6. Fibres with good bond characteristics and high specific surface are very effective in controlling both deflection and cracking width.

References

Al-Kubaisy, M. A., & Zamin Jumaat, M. (2000). *Flexural behaviour of reinforced concrete slabs with ferrocement tension zone cover. Construction and Building Materials, 14(5), 245–252.*

Bhikshma, V., Ravandekishore, & Srinivas, R. (2011). *Durability of Polymer and Fly Ash Modified Ferro Cement Elements. Procedia Engineering, 14, 2642–2649.*

Eskandari, H., & Madadi, A. (2015). *Investigation of ferrocement channels using experimental and finite element analysis. Engineering Science and Technology, an International Journal, 18(4), 769–775.*

Ibrahim, H. M. H. (2011). *Shear capacity of ferrocement plates in flexure. Engineering Structures, 33(5), 1680–1686.* doi:10.1016/j.engstruct.2011.02.004

Ismail, Z. Z., & AL-Hashmi, E. A. (2008). *Use of waste plastic in concrete mixture as aggregate replacement. Waste Management, 28(11), 2041–2047.*

Kaish, A. B. M. A., Jamil, M., Raman, S. N., Zain, M. F. M., & Nahar, L. (2018). *Ferrocement composites for strengthening of concrete columns: A review. Construction and Building Materials, 160, 326–340.*

Kou, S. C., Lee, G., Poon, C. S., & Lai, W. L. (2009). *Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes. Waste Management, 29(2), 621–628.*

Marzouk, O. Y., Dheilly, R. M., & Queneudec, M. (2007). *Valorization of post-consumer waste plastic in cementitious concrete composites. Waste Management, 27(2), 310–318.*

Masood, A., Arif, M., Akhtar, S., & Haquie, M. (2003). *Performance of ferrocement panels in different environments. Cement and Concrete Research, 33(4), 555–562.*

Mughal, U. A., Saleem, M. A., & Abbas, S. (2019). *Comparative study of ferrocement panels reinforced with galvanized iron and polypropylene meshes. Construction and Building Materials, 210, 40–47.*

Yerramala, A., Ramachandurdu, C., & Bhaskar Desai, V. (2013). *Flexural strength of metakaolin ferrocement. Composites Part B: Engineering, 55, 176–183.*

Naik, T. R., Singh, S. S., Huber, C. O., & Brodersen, B. S. (1996). *Use of post-consumer waste plastics in cement-based composites. Cement and Concrete Research, 26(10), 1489–1492.*

Saikia, N., & de Brito, J. (2012). *Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Construction and Building Materials, 34, 385–401.*
Sakir, S., Raman, S. N., Kaish, A. B. M. A., & Mutalib, A. A. (2016). *Self-flowing mortar for ferrocement in strengthening applications. Perspectives in Science, 8, 673–676.*

Qeshta, I. M. I., Shafigh, P., & Jumaat, M. Z. (2016). *Research progress on the flexural behaviour of externally bonded RC beams. Archives of Civil and Mechanical Engineering, 16(4), 982–1003.*

Yerramala, A., Ramachandurdu, C., & Bhaskar Desai, V. (2013). *Flexural strength of metakaolin ferrocement. Composites Part B: Engineering, 55, 176–183.*

Yerramala, A., Ramachandurdu, C., & Bhaskar Desai, V. (2013). *Flexural strength of metakaolin ferrocement. Composites Part B: Engineering, 55, 176–183.*

Yardim, Y. (2018). *Review of Research on the Application of Ferrocement in Composite Precast Slabs. Periodica Polytechnica Civil Engineering.*