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Effect of Fly Ash and Fine-Sand Addition on the Mechanical and Thermal Properties of Modified Adhesive

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ABSTRACT

This study presents an exploratory investigation into the mechanical and thermal properties of a modified adhesive (high adhesive, Sikadur®-330) when mixed with fly ash or a combination of fly ash and fine-sand at various ratios, as well as the adhesive's performance under high temperatures of 250℃. A series of physical tests, including compressive strength, consistency, modulus of rupture, density, and ultrasonic pulse velocity, were conducted alongside thermal assessments, such as final and initial shrinkage, linear expansion coefficient, and heat of reaction measurements. The results demonstrate that the incorporation of fly ash and fine-sand significantly enhances the adhesive's thermal properties by reducing both final and initial shrinkage, minimizing the linear expansion coefficient, and attenuating the heat of reaction. Furthermore, the mechanical properties of the adhesive were observed to improve upon exposure to high temperatures of 250℃. The addition of fine-sand and fly ash to the adhesive not only reduced costs but also led to a notable increase in the modulus of rupture and compressive strength. Consequently, the optimal ratio of adhesive, sand, and fly ash was determined to be 1:1:1 by weight, considering improvements in mechanical and thermal properties, cost reduction, and preserved workability.

1. INTRODUCTION

Epoxy resins, known for their relatively high strength, are commonly employed to bond steel or fibers to concrete, offering various engineering benefits. Available in numerous types, epoxy resins typically consist of two main components: resin and hardener. The technique of strengthening concrete members using carbon fiber reinforced polymers (CFRP) bonded with epoxy has been demonstrated to be effective [1]. However, this method also presents certain drawbacks, including propagation nearness, thermal incompatibility with original concrete, and restrictions pertaining to minimum application temperature and working environment [2].

Characterized by its brittle nature and weak resistance to crack propagation, pure epoxy's properties have been the subject of numerous studies investigating the improvement of epoxy resin mechanical properties through the addition of inorganic fillers [3]. Yano [4] reported that integrating an organic polymer with an inorganic network can increase the mechanical properties of bulk materials. The use of nanoparticle-reinforced adhesive materials has recently emerged as a subject of great interest in engineering and materials science, owing to nanoparticles' exceptional properties, such as enhanced adhesive tensile strength, which result from permitting thin layer bond lines and thereby reducing the risk of embrittlement within the bulk adhesive material [5].

Investigations have been conducted into the mechanical properties of epoxy fillers containing varying amounts of admixed copper and aluminum powders, each with a range of grain sizes. The adhesive employed was a toughened, single-part epoxy. Test results revealed improvements in tensile strength, shear strength, peel force, impact strength, and fatigue strength when compared to adhesives without powder additions [6]. Blanksvärd [7] proposed an alternative to epoxy filled with metallic powders by using a mix of fiber, polymer, superplasticizer, and mortar as an adhesive material, which is more cost-effective and easier to control in terms of mixing ratios.

The thermal expansion of epoxy and associated thermal stresses arise from variations in service temperature and low temperature during curing. It is important to note that different structural elements are exposed to a wide range of temperatures [8, 9]. Furthermore, the mechanical and thermoplastic properties of adhesives containing nitrile-butadiene-styrene (ABS) were affected by temperature, with the experimental range spanning from 50℃ to 800℃ in 20℃ increments. Degradation kinetics were measured using thermogravimetric analysis (TG), and the addition of ABS was found to improve tensile, toughness, and thermoplastic properties as temperatures increased [10].

This study aims to develop an economical adhesive material by combining a known adhesive with cost-effective materials, such as fine-sand and fly ash. The addition of these materials reduces the adhesive ratio in the mixture while maintaining its strength, resulting in a significant cost reduction and enhanced properties. The research investigates the efficiency of adding fine materials (fly ash and sand) to the adhesive, exploring whether this improves or maintains adhesive properties while reducing costs. Furthermore, the study examines the effect of these additions on the mechanical and thermal properties of the adhesive under normal and high temperature conditions.

The potential for economizing adhesive usage and its application in strengthening beams without high-temperature protection due to its inherent resistance to high temperatures is also explored.

2. MATERIALS AND MIX PROPORTIONS

2.1 Materials

2.1.1 Adhesive

A paste with a property of high adhesive bonding from Sika company known as Sikadur®-330 with density 1.31 kg/Land have medium viscosity material for mix component A (resin) and B (hardener). Adhesive properties as in Table 1.

Table 1. Properties of adhesive Sikadur®-330

Properties	Description
Ratio of mix (A:B) by weight	1:4
Pot life	+15℃: 90 min.
+ 35℃: 35 min. Open time	+ 35℃: 30 min.
Application Temp.	+15℃ to +35℃
Tensile strength	30 N/mm^2 at (Curing 7 day, +23℃)
Flexural	3800 N/mm^2 at (Curing 7 day, +23℃)
℃: Celsius degrees	

2.1.2 Fine-Sand

Well graded sand was sieved from 300 µm to 75µm sieve opening used, with a fineness modulus and a specific gravity respectively of 1.64 and 2.60, and absorption capacity equal to 1.3%. Before using, the sand is washed well and dried and the sulphate content equal to 0.05%.

2.1.3 Fly ash

Properties of fly ash were used in accordance with the British standard EN 450:1995, where the properties of fly ash given in Table 2.

Table 2. Physical properties and chemical composition of fly ash

Property	Content, %
Residue on sieve 45 µm	30
Loss on ignition	4
Sulphuric anhydride	2
Silica	30
Chloride	0.05
Free calcium oxide	0.043
Activity index on 28 Day	87
Activity index on 90 Day	88
Soundness	9

2.2 Mix proportions

Table 3 presented the adhesives mortar proportions used in this investigation. Mixing ratio of part A to part B of adhesive was (1:4). Firstly, part B must be mixed with fly ash or sand then mix part A to make sure reducing reaction temperature and optimizing workability. After a mixture of the materials were casting adhesive cubes (50×50×50 mm) and prisms (40×40×160 mm), the models leave for seven days to dry and harden permanently.

Some of the Cubes were exposed to high temperatures 250℃ to evaluate the change in mechanical properties of adhesive.

2.3 Consistency of adhesive

Flow consistency of adhesive mortar was expressed according to ASTM C 230 used procedures of standard previously mentioned [11] and standard C 1437 used to flow table test which is used for computing the consistency of the adhesive. The test procedure consists of measuring the increase of the base diameter of cone mold containing adhesive mortar which is result from raised and dropped of cone top through an appointed height used means of a rotating cam before removing the mold from the adhesive then times in 15 second the table is dropped 25 times. The increasing in the average base diameter of the mortar as a percentage of according to an original diameter represents flow of the mortar.

3. TESTS

3.1 Mechanical properties

Compressive strength had been measured to cubes in 3, 4, 5, 6, 7, and 14 days, as well as compressive strength measured for cubes age of fourteen days after it exposing to high temperature 250℃, by placing specimens in the oven for three hours [12]. Prisms specimens were used to measure the modulus of rupture in 7 days.

3.2 Thermal properties

The temperature of the adhesive interaction, with or without the additive, was monitored. The temperatures immediately measured in the first hours from mixing.

The value of linear expansion coefficients and the shrinkage of adhesive prisms during the first hours are measured and for the final hardening after seven days of casting models at the temperature rises by 40℃ of the temperature of the laboratory, also the shrinkage measurement while reduce the temperature by 40℃ where they are fixing demec point (node have hole for installing the mechanical strain gauge) on the adhesive prisms after casting models directly to measure the shrinkage of the casting from the beginning for many hours until change of the shrinkage and the expansion stabile.

4. RESULTS AND DISCUSSION

4.1 Consistency of adhesive

By increasing the additive ratio, the flow of mixing decrease and the final flow convergent approximately for every ratios but, the initial flow for mixes contain fly ash alone was different where increase of percentage of fly ash the flow decreased, due to the surface area of fly ash were large. This is because of the reduction the adhesive percentage in the mixing (see Table 3 for mixing ratio), in another ratios containing the fine-sand the initial and final flow was a decrease with an increase in the ratio of fly ash.

Table 3. Mixing ratio, flow values, density and coefficients of linear expansion

Sample	Mixing Ratio, wt%			Flow, %		Density	CTEa
	Epoxy	Sand	Ash	Initial	Final	kg/m³	1/°C
ESF1	1	0	0	135	195	1320	95.7×10-4
ESF2	1	0	1	0	150	1610	63.0×10-4
ESF3	1	1	0.25	120	170	1665	74.2×10-4
ESF4	1	1	0.5	110	160	1680	66.5×10-4
ESF5	1	1	1	0	140	1840	57.2×10-4

CTEa: A Coefficient of linear expansion

4.2 Mechanical properties

4.2.1 Compressive strength

Test results described some of including in, Figure 1 have shown that the developing the strength adhesive mortar for periods of between (3 – 14) days within different proportions of adhesive, fly ash and sand by weight of adhesive seems to be feasible. The increase in compressive strength (fcu) was range between 96 to 101 MPa at 14 days. The optimum ratio namely the ESF5 mixes were containing a combination of adhesive, sand, and fly ash, with a ratio (1:1:1) showed a 4.75% increase by compressive strength percent to control mixes ESF1 (neat adhesive), the increase due to the fly ash work as a filler for voids between the sand particles lead to increasing the density of adhesive mortar. But the other mixes decrease compressive strength compared to control mixes with ratios up to 8%, because the fly ash ratio was an inadequate to fill all the voids between the sand particles.

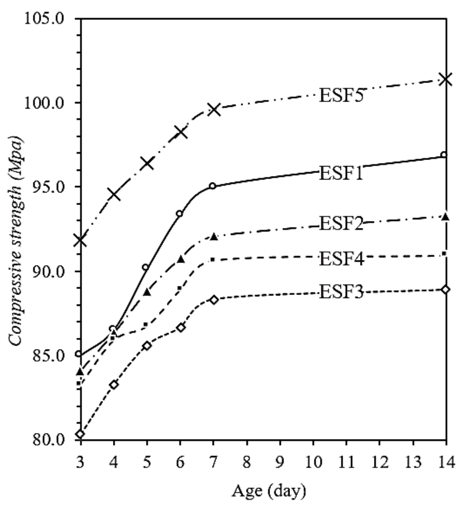

Figure 1. The effect age on the compressive strength for several mixes

Curing the adhesive by high temperature (250°C) lead to increasing the compressive strength, observed in Figure 2 due to annealing phenomenon, which represents an increase in strength because of decrease the free spaces while exposed to temperature [13].

The control sample (neat adhesive) showed many cracks and carbonization in the inverse of other samples containing fly ash and/or sand, where these additives improve the adhesive resistance to high temperature and increasing the temperature of glass transision (Tg).

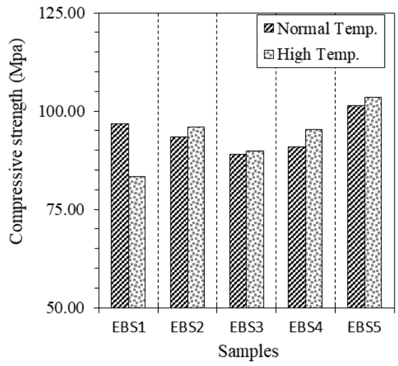

Figure 2. The effect of temperature on the compressive strength with 14 day age

4.2.2 Modulus of rupture

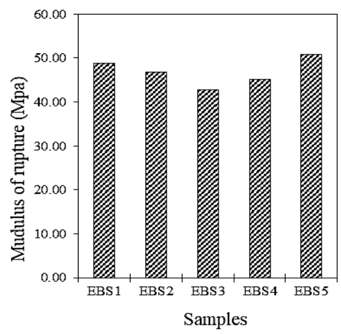

Figure 3. (a) The effect of mixing ratio on the modulus of rupture

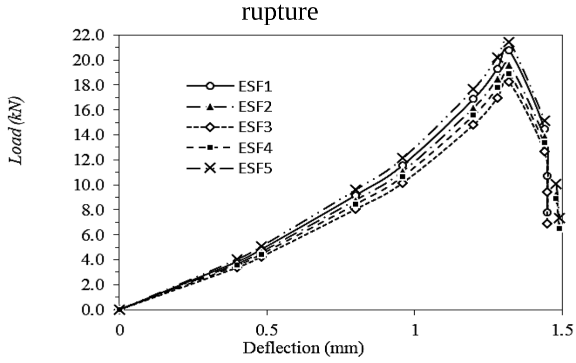

Figure 3. (b) Load-deflection curve for adhesive prisms under flexural load

Figure 3-a shows that the effect the added ratio on the modulus of rupture (fr). The Figure 3-a shows that a best ratio of adhesive, sand and fly ash by weight of the adhesive is (1:1:1) respectively, namely the ESF5 mixes. Figure 3-b represents the curve of load-deflection for prisms consisting of adhesive under the effect of central flexural load.

4.2.3 Density and Ultrasonic pulse velocity (UPV)

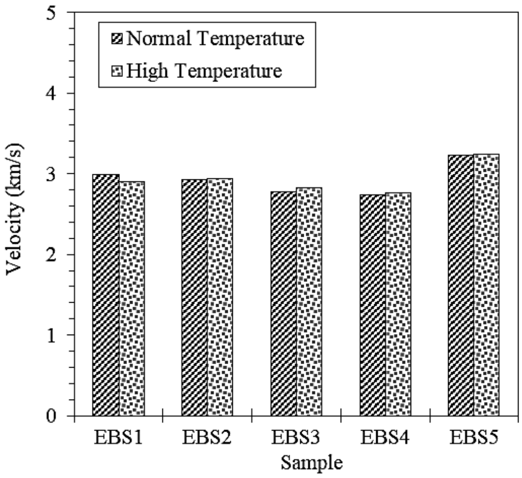

Figure 4. The effect of mixing ratio on the Ultrasonic Pulse Velocity (UPV)

The results of UPV for adhesive cubes at 14 days age before and after curing by high temperature as shown in Figure 4, while the densities for all mixes are shown in Table 3. It can be noticed that the speed wave in the samples increases with increasing the additive ratio, but the control mixes ESF1 have high speed due to the absence of any voids, also notes the mixes ESF5 owns the largest density due to a good gradient for the additives which reduces the voids.

4.3 Thermal properties

4.3.1 Mixing temperature

Mixing adhesive components with both parts results high reaction temperature through the first hour, as shown in Figure 5. The addition of fine-sand or fly ash led to reduce reaction temperature. This is because of low coefficient of thermal conductivity for the additive and the additive work as filler not as active materials.

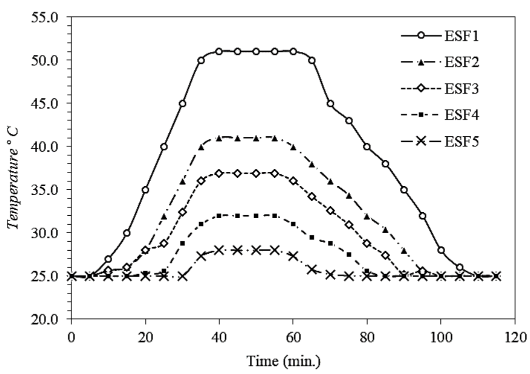

Figure 5. Effect of fly ash and sand on the reaction temperature

4.3.2 Shrinkage during the primary solidification

During the first hour from start mixing, occurs an increase in temperature with a short time result in shrinkage and expansion in the adhesive, the shrinkage stops after almost 24 hours. Figure 6 observes that the additive is working to reduce the visible shrinkage and expansion in adhesive, while Figure 7 shows the shrinkage of an adhesive during at first hour from start mixing. The first read taken after one hour from casting to hardening enough for adhesive. This additive lead to reduced ultimate shrinkage by 81.7% when adding the fly ash only to adhesive with ratio (1:1), but mixtures adhesive, sand and fly ash with ratios (1:1:0.25), (1:1:0.5), and (1:1:1) by weight of the adhesive, the reduce were 63.5%, 72.6%, and 75.9%, respectively.

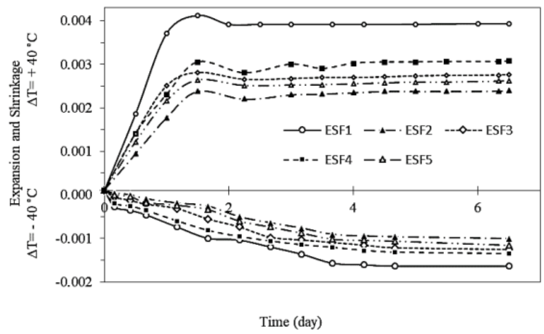

Figure 6. Shrinkage and expansion for epoxy prism during 7-days age

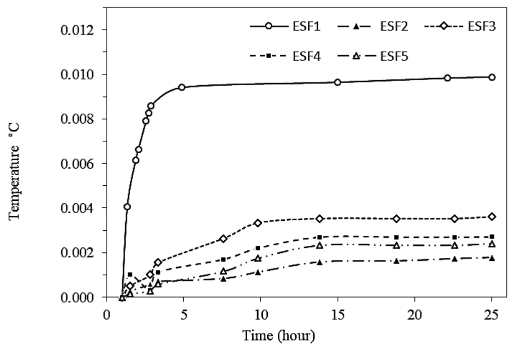

Figure 7. Initial shrinkage for several mixes during the first 25 hours

4.3.3 Shrinkage and expansion of hardened adhesive

Figure 6 shows that the addition of fly ash and/or sand to the adhesive decreases shrinkage and expansion for mixes ESF2, ESF3, ESF4, and ESF5 compared with control mix ESF1, by 34.2%, 22.4%, 30.5%, and 40.2%, respectively for expansion due to raise in the temperature by 40℃ and by 36.8%, 21,8%, 16.7%, and 28.2% respectively with decreasing the temperature at 40℃ from temperature of the laboratory. These additions increase the coefficient of linear expansion for the prisms which calculated according to ASTM E228 [11], the results as shown in Table 3 [14, 15].

5. CONCLUSIONS

According to the test results of the current study, the following conclusions can be drawn:

1.Modified adhesive use in strengthening the beams without protecting them from high temperatures due to its resistance to high temperature.

2.This additive reduces the ratio of adhesive in mix with almost keeping on the strength of the adhesive, and to achieve a larger decreasing in the cost of the adhesive, also to enhancing that properties.

3.Added the fine material must mix with the resin part of the adhesive before mixing with a hardener part to improve workability and decrease the temperature of reaction.

4.Increasing the ratio of fine materials reduces the flow of mixing, and the best weight ratio for adhesive, sand and fly ash were 1:1:1.

5.Added the fine material to the adhesive reduce of a high interaction temperature, result in mix two parts of adhesive and a large reduce shrinkage during the 1st hour of interaction until 24 hours. The main important conclusion was impossible to mixing a large amount of epoxy without using fine materials.

6.Adding sand or fly ash to adhesive develop compressive strength and MOR, and also increases the compressive strength of adhesive after curing by high certain temperature.

7.Adding fine-sand or fly ash to adhesive change the compression failure for cubes from failure with fragment and sound to progressively and silent failure without fragment.

8.The UPV increasing with increases in additive ratio.

9.Adding the fine material to adhesive reduces coefficients of linear expansion.

10.Using fine-sand and fly ash for the optimum ratio decrease the large shrinkage occurred in epoxy alone and a noticeable reducing at the cost at about to third the cost of the original adhesive.

REFERENCES

[1] Landel, R.F., Nielsen, L.E. (1993). Mechanical properties of polymers and composites. CRC press.

[2] Täljsten, B., Blanksvärd, T. (2007). Mineral-based bonding of carbon FRP to strengthen concrete structures. Journal of Composites for Construction, 11(2): 120-128. https://doi.org/10.1061/(ASCE)1090-0268(2007)11:2(120)

[3] Ochi, M., Takahashi, R., Terauchi, A. (2001). Phase structure and mechanical and adhesion properties of epoxy/silica hybrids. Polymer, 42(12): 5151-5158. https://doi.org/10.1016/S0032-3861(00)00935-6

[4] Yano, S. (1996). Physical properties of poly(vinyl alcohol)/silica hybrid prepared by sol-gel process. Kobunshi Ronbunshu, 53: 218-224. http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=3091978

[5] Jacobs, O., Xu, W., Schädel, B., Wu, W. (2006). Wear behavior of carbon nanotube reinforced epoxy resin composites. Tribology Letters, 23(1). https://doi.org/10.1007/s11249-006-9042-7

[6] Kilik, R., Davies, R. (1989). Mechanical properties of adhesive filled with metal powders. International Journal of Adhesion and Adhesives, 9(4): 224-228. https://doi.org/10.1016/0143-7496(89)90065-1

[7] Blanksvärd, T. (2007). Strengthening of concrete structures by the use of mineral-based composites (Doctoral dissertation, Civil Engineering, Luleå University of Technology, Sweden).

[8] Sivasakthi, M., Jeyalakshmi, R., Rajamane, N.P. (2021). Fly ash geopolymer mortar: Impact of the substitution of river sand by copper slag as a fine aggregate on its thermal resistance properties. Journal of Cleaner Production, 279. https://doi.org/10.1016/j.jclepro.2020.123766

[9] Barnat-Hunek, D., Grzegorczyk-Frańczak, M., Klimek, B., Pavlíková, M., Pavlík, Z. (2021). Properties of multi-layer renders with fly ash and boiler slag admixtures for salt-laden masonry. Construction and Building Materials, 278. https://doi.org/10.1016/j.conbuildmat.2021.122366

[10] Abad, M.J., Barral, L., Cano, J., Lopez, J., Nogueira, P., Ramírez, C., Torres, A. (2001). Thermal decomposition behavior and the mechanical properties of an epoxy/cycloaliphatic amine resin with ABS. European Polymer Journal, 37(8): 1613-1623. https://doi.org/10.1016/S0014-3057(01)00036-2

[11] Ann, A., MI (2005). ASTM book of standards. Cement, lime, gypsum. American Society for Testing Materials, 04-02. https://www.astm.org/.

[12] Al-Safy, R., Al-Mahaidi, R., Simon, G.P., Habsuda, J. (2012). Experimental investigation on the thermal and mechanical properties of nanoclay-modified adhesives used for bonding CFRP to concrete substrates. Construction and Building Materials, 28(1): 769-778. https://doi.org/10.1016/j.conbuildmat.2011.09.009

[13] Odegard, G.M., Bandyopadhyay, A. (2011). Physical aging of epoxy polymers and their composites. Journal of Polymer Science Part B: Polymer Physics, 49(24): 1695-1716. https://doi.org/10.1002/polb.22384

[14] Al-Safy, R., Al-Mahaidi, R., Simon, G.P., Habsuda, J. (2012). Experimental investigation on the thermal and mechanical properties of nanoclay-modified adhesives used for bonding CFRP to concrete substrates. Construction and Building Materials, 28(1): 769-778. https://doi.org/10.1016/j.conbuildmat.2011.09.009

[15] Odegard, G.M., Bandyopadhyay, A. (2011). Physical aging of epoxy polymers and their composites. Journal of Polymer Science Part B: Polymer Physics, 49(24): 1695-1716. https://doi.org/10.1002/polb.22384