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Performance of Polyester Grouted Connector for Splicing of Reinforcement Bars

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Abstract: The research aims to investigate the viability of employing polyester grout as a bonding agent for the splicing of reinforcement bars. 0.43 and 1 binder-to-filler ratio were examined. The process of splicing reinforcement bars under tension using a polyester grouted splice connector is elucidated. Through direct tension tests, the optimal mix design and required length of the splicing sleeve were identified. The findings indicate that the polyester grouted connector with a 0.43 binder-to-filler ratio performs satisfactorily for the splicing of tensile reinforcement bars. Specifically, a spiral length of 250 mm with an embedded length of 125 mm is demonstrated to achieve the full strength of the spliced bar.

Keywords: Polyester Grout, Fly Ash, Grouted Splices, Tensile Strength

Introduction

A spliced grouted connector is a construction device, particularly prevalent in civil engineering, employed to link two structural elements. This type of connector is utilized to join reinforcing bars, commonly known as rebar, within concrete structures. Its purpose is to ensure the stability and overall integrity of the structure by establishing a robust and reliable connection between the bars. The history of grouted connectors for splicing dates back to the late 19^{th} and early 20^{th} centuries, coinciding with the development of reinforced concrete. As construction methods progressed, the efficient and dependable connection of reinforcing bars became increasingly crucial. This necessity led to the development of various types of splicing connectors, including grouted connectors, which have now become a standard in modern construction practices.

These connectors have found widespread application in diverse construction projects, such as bridges, buildings and various infrastructures, offering a range of benefits; including strengthening the integrity of the structure, facilitating improved load transfer and enhancing overall durability. Moreover, they are engineered to withstand diverse environmental conditions like moisture and corrosion, making them adaptable to a broad spectrum of applications.

In recent years, advancements in the design and manufacturing of grouted connectors for splicing have yielded new and improved products boasting enhanced performance and reliability. These developments are propelled by ongoing research and development initiatives in the field of civil engineering, spurred by the demand for more efficient and sustainable construction practices. Overall, grouted connectors for splicing have played a pivotal role in advancing construction technology and continue to be an essential component in the development of safe and durable structures (ACI, 2014; ASTM, 2019).

Various connection types, including beam splice, column splice and beam-to-column connections, rely on grouted connections to maintain and augment their structural integrity and stability. The effectiveness of these grouted connections is contingent upon both confinement action and the strength of the grout. The specification of high-strength grout serves a dual purpose: Firstly, to enhance the bond between the grout and the bar, ensuring that stresses in the reinforcement bars can be transferred effectively to the adjacent material, thus favoring the desired failure mode of bar fracture over bar pull-out; and secondly, to minimize the required embedment lengths for grouted-in bars (Ling *et al*., 2012).

Traditional cement grouts, typically employed in grouted splice connectors, come with several drawbacks, such as extended curing periods and a gradual progression in strength. An emerging alternative is Polymer grout (PM) or resin mortar, a modern composite formed by blending inorganic aggregates (such as sand) with a resin binder (Raymond and Sauntson, 1987; Mohammed *et al*., 2015). Moreover, crucial additives in polymer formulations include microfillers like fly ash, which serve to diminish the rate of the curing reaction and reduce the exothermic degree (Petrie, 2006; Fadiel *et al*., 2023). PM exhibits superior strength and durability compared to cement grout. Its most notable advantage lies in its rapid curing, typically taking only a few hours, while cement grouting mix requires more time sometimes reaching weeks to achieve desired strength (Rebeiz *et al*., 1996). One outcome of the effort to lessen the harmful effects of byproducts and solid waste materials is the use of fly ash as filler material. Fadiel *et al*. (2022); Fadiel (2015); Abu-Lebdeh *et al*. (2014); Fadiel and Abu-Lebdeh (2021); Fadiel (2022; 2013); Fadiel *et al*. (2014).

There is a lack of research on the utilization of polymer grout as a bonding material in grouted splice connectors. In 1970, markested and Johansen proposed the utilization of polymer mortar as a bonding material for a steel pipe sleeve. Various resin types, including polyester and epoxy, were combined with fine sand to create the filler in the polymer paste. The conducted research demonstrated the successful use of sleeve spliced with polymer mortar for splicing steel bars. However, it's worth noting that the temperature range for utilizing epoxy mortar in splicing reinforcement steel bars under tensile stresses could be constrained due to an observed increase in creep with the change in temperature (Navaratnarajah, 1983). The heightened creep effects observed in the markested and Johansen study may be attributed to the creep occurring within the resin mortar situated between the sleeve and the deformed steel bars. This phenomenon is associated with both a high reaction rate and a significant exotherm, factors that depend on the properties of the filler and the quantity of resin present in the polymer mortar.

In this experimental study, a bonding material for grouted splice connectors was created using polyester grout containing 30 and 50% polyester resin, along with the inclusion of fly ash. This formulation aimed to minimize the degree of exotherm and the rate of cure response. The polyester grouted splice connectors underwent testing under tensile load to evaluate their effectiveness. Additionally, the goal of the investigation was to ascertain the ideal sleeve length required to achieve the highest possible strength for the spliced bar in the polyester grout.

Materials and Methods

Six specimens of polyester grouted splices were tested under increasing tensile loads. Additionally, three high-strength steel bars (Y16) were evaluated to serve as a reference for the behavior of an ideal grouted splice, providing a basis for comparison with the proposed polyester grouted splice specimens.

Materials and Test Specimens

Two different mixtures of polyester grout, identified as mix A and B, were employed as bonding materials. These polyester grout mixes were produced using a combination of polyester binder, sand and fly ash as fillers. The proportions for mixes A and B involved a mix of polyester and filler in the ratio of 30:70 and 50:50 parts by volume, respectively. Fly ash made up 14% of the mixture's total volume. The polyester grouted splice connectors were made by joining high-strength deformed bars measuring 16 mm with a steel spiral reinforcing bar that had an external reinforcement bar welded to it. The dimensional configurations and specifications of the connector are illustrated in Fig. 1 and Table 1.

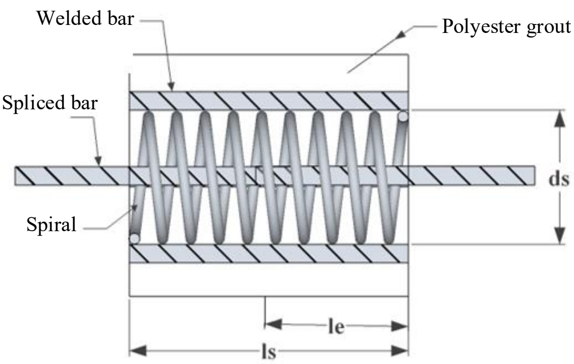


Fig. 1: Details of polyester grouted splice specimens

Table 1: Details of specimens

Specimens	Ds (mm)	Ls (mm)	Le (mm)	Binder /filler ratio	Proportion of binder to filler	Mix ID
D33-L150-A	33	150	75	0.43	30:70	A
D33-L200- A	33	200	100	0.43	30:70	A
D33-L250- A	33	250	125	0.43	30:70	A
D33-L150- B	43	150	75	1.00	50:50	B
D33-L200- B	43	200	100	1.00	50:50	B
D33-L250- B	43	250	125	1.00	50:50	B

Fig. 2: Tensile load test setup

Test Setup

Steel bars are first embedded into the spiral from both ends before applying the polyester grout which serves as the bonding material. Before testing the specimens, strain gauges were attached to the spliced bars at a distance of 16 mm, extruding from the grouted spiral connections. Figure 2 illustrates the setup for the tensile test. The collected data from the testing encompassed the load applied, displacement and strain in the steel bar. Additionally, the laboratory test determined the compressive strength of the polyester grout.

Results and Discussion

Figures 3-4 present the load-displacement curves and modes failure observed in the tested polyester grouted connectors. Table 2 illustrates the ultimate tensile load, ultimate stress and ultimate strain for all tested connectors.

According to Figs. 3-4, it is evident that for connectors using Mix A as the bonding material, two distinct behaviors are observed. Firstly, specimens D33-L200-A and D33-L150-A exhibit insufficient bonds and fail in a brittle mode, with bars slipping out of the sleeve before the spliced bars yield. Secondly, specimen D33-L250-A, with a bar-embedded length of 125 mm, demonstrates an acceptable bond and fails in a ductile manner, with the spliced bar fracturing outside the sleeve. The spliced bars within the sleeve yielded and lengthened before fracturing the outer side of the sleeve. In contrast, grouted splice connectors D43-L250-B, D43-L200-B and D43-L150-B, which utilize mix B as the bonding material, fail due to the splitting of the surrounding grout, resulting in a complete loss of load-carrying capacity.

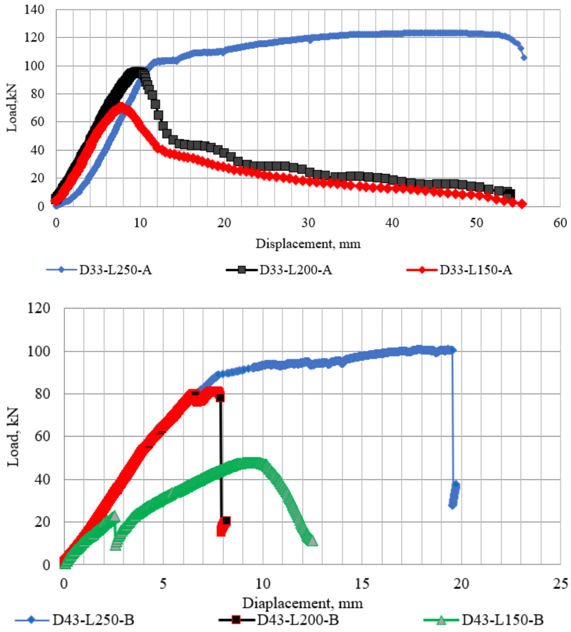
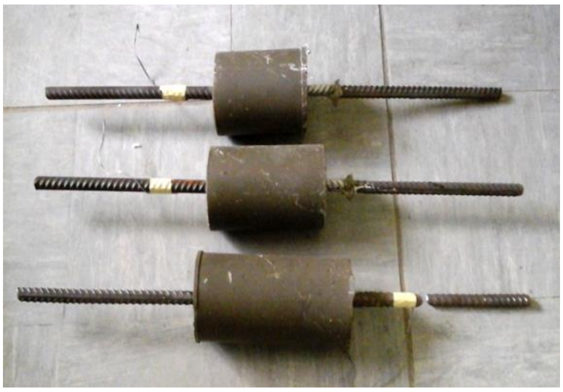
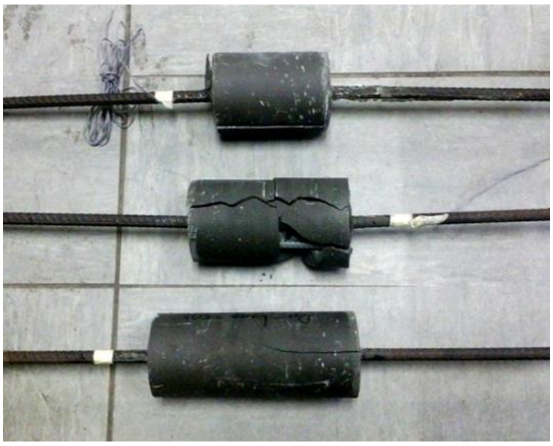


Fig. 3: Load vs. displacement curve for tested connectors till failure



(a)



(b)

Fig. 4: Mode of failure for tested specimens; (a) Mix A with 30% polyester resin; (b) Mix B with 50% polyester resin

Table 2: Results of tensile load test

Specimens	Ultimate tensile load (kN)	Ultimate stress (N /mm^2)	Ultimate strain (mm/mm)	Failure modes
D33-L150- A	70.310	337.960	1253*10^{-6}	Pull out
D33-L200- A	95.440	477.120	1930*10^{-6}	Pull out
D33-L250- A	123.500	612.060	3550*10^{-6}	Bar fractured
D43-L150- B	47.926	238.285	945*10^{-6}	Splitting crack
D43-L200- B	81.282	404.459	2149*10^{-6}	Splitting crack
D43-L250- B	100.832	501.752	2930*10^{-6}	Splitting crack

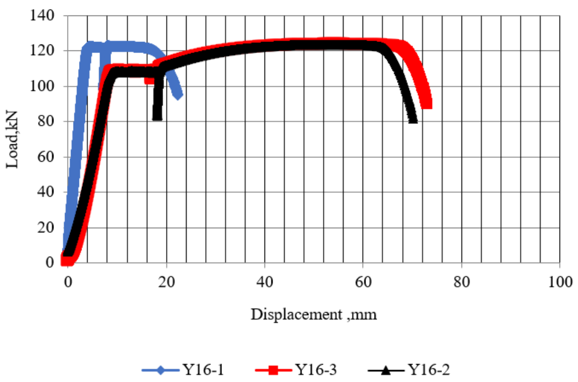


Fig. 5: Load- Load-displacement curve for control specimens

(a)

(b)

Fig. 6: Failure modes of polyester grout specimens due to compression load; (a) Mix A with 30% polyester; (b) Mix B with 50% polyester

Referring to Table 2 and Fig. 5, specimens D33-L200-A, D33-L150-A, D43-L200-B and D43-L150-B, with bar anchorage lengths of 75 and 100 mm, exhibited ultimate tensile stresses in the spliced bar lower than the specified yield stress of 500 N/mm². The strain in the spliced bar did not reach values below 2300×10^{-6} mm/mm. In contrast, specimens D33-L250-A and D43-L250-B experienced maximum stresses in the bars of 612.06 and 501.752 N/mm², respectively, surpassing the yield stresses of the deformed bars which set at 500 N/mm². Additionally, the maximum strains recorded in these bars, 3550×10^{-6} and 2930×10^{-6} mm/mm, significantly exceeded the yield strain of 2300×10^{-6} mm/mm. This suggests that specimen D33-L250-A provided the full tensile strength of the connected steel bars. The behavior of this specimen closely resembles that of the control specimens representing an effective grouted splice connector, demonstrating stages of elasticity, yielding and bar fracture failure. Therefore, the optimal sleeve length essential to achieve the spliced bar's ultimate strength by using polyester grout as the bonding material was determined to be 250 mm, with an anchorage length of 125 mm. Additionally, despite Mix A having a compressive strength of 61.4 MPa, lower than the compression strength of Mix B at 75.5 MPa, specimen D33-L250-A exhibited an undesirable failure mechanism, specifically splitting failure due to an increase in creep associated with the higher amount of polyester (Fig. 6).

With an increase in bar embedded length, the polyester grouted spiral connections produce more bond capacity. To withstand the tensile load inside the spiral, the spiral connections need a minimum bar embedded length that is around six times the bar diameter. The bond capacity of polyester grouted spiral connections improves as the spiral diameter decreases. A decrease in spiral diameter enhances the confinement stress acting on the grouted connection, hence increasing bond capacity.

Conclusion

In this investigation, polyester grouted connectors underwent testing with increasing tensile loads to evaluate the viability of using polyester grout as a bonding material for such connectors. Based on the test results and the subsequent discussion, it can be concluded that fast-setting polyester grout holds promise as a potential material for filling joints and connections. Moreover, by making use of the spiral's confinement and the high strength of polymer grout, the necessary development length can be drastically shortened to about eight times the diameter of the bar. This is around 22.3% of the anchorage length that BS8110 recommends, which is 35 times the bar's diameter (BS8110, 1997).

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Author's Contributions

Ashraf Fadiel, Nuria Mohammed, Ahmad Baharuddin Abdul Rahman and Esam Abu Baker Ali: Conducted laboratory experiments, analyzed the data and participated in written the manuscript.

Taher Abu-Lebdeh: Provided the research topic, guided the research development, experimental plan and data analysis and participated in written the manuscript.

Ethics

The authors would to disclose that Dr. Taher Abu-Lebdeh and Ashraf Fadiel (Co-authors) are members of the editorial board for the American journal of engineering and applied sciences.

References

Abu-Lebdeh, T., Fini, E., & Fadiel, A. (2014). Thermal conductivity of rubberized gypsum board. *Am. J. Eng. Appl. Sci*, *7*, 12-22.

ACI. (2014). ACI 318-14. Building code requirements for structural concrete. *American Concrete Institute*. http://aghababaie.usc.ac.ir/files/1506505203365.pdf

ASTM. (2019). Standard specification for epoxy-coated steel reinforcing bars. ASTM A775/A775M-19, *ANSI Webstore*. https://webstore.ansi.org/standards/astm/astma775a775m19

BS8110, B. S. I. (1997). Structural use of concrete, part 1: Code of practice for design and construction. *British Standards Institution, UK*. https://www.scribd.com/document/368477731/BS-8110-1997-Part-1-Structural-Use-of-Concrete

Fadiel, A. (2013). *Use of Crumb Rubber to Improve Thermal Efficiency of Construction Materials* (Doctoral dissertation, North Carolina Agricultural and technical state university). https://digital.library.ncat.edu/theses/316

Fadiel, A. (2015, December). A review of properties of concrete containing crumb rubber from used tires. *In Proceedings of the 13th Arab Structural Engineering Conference, Blida, Algeria* (13-15). https://www.researchgate.net/publication/320274357_A_review_of_properties_of_concrete_containing crumb rubber from used tires In Arabic

Fadiel, A. (2022). Estimating of compressive strength of rubberized concrete using destructive and non-destructive test methods. *Proceedings of the NCBMSE.*

Fadiel, A. A., Abu-Lebdeh, T., & Petrescu, F. I. T. (2022). Assessment of woodcrete using destructive and non-destructive test methods. *Materials*, *15*(9), 3066. https://doi.org/10.3390/ma15093066

Fadiel, A. A., Mohammed, N. S., Rahman, A. B. A., Ali, E. A. B., Abu-Lebdeh, T., & Petrescu, F. I. T. (2023). Effect of fly ash on mechanical properties of polymer resin grout. *Biomimetics*, *8*(5), 392. https://doi.org/10.3390/biomimetics8050392

Fadiel, A., & Abu-Lebdeh, T. (2021). Mechanical properties of concrete including wood shavings as fine aggregates. *Am. J. Eng. Appl. Sci*, *14*, 478-487. https://doi.org/10.3844/ajeassp.2021.478.487

Fadiel, A., Al Rifaie, F., Abu-Lebdeh, T., & Fini, E. (2014). Use of crumb rubber to improve thermal efficiency of cement-based materials. *American Journal of Engineering and Applied Sciences*, *7*(1), 1-11. https://www.academia.edu/82589694/Use_of_Crumb_Rubber_to_Improve_Thermal_Efficiency_of_Cement_Based_Materials?f_ri=55

Ling, J. H., Rahman, A. B. A., Ibrahim, I. S., & Hamid, Z. A. (2012). Behaviour of grouted pipe splice under incremental tensile load. *Construction and Building Materials*, *33*, 90-98. https://doi.org/10.1016/j.conbuildmat.2012.02.00

Mohammed, N. S., Abd Rahman, A. B., Khalid, N. H. A., & Ahmed, M. (2015). Experimental study of splitting tensile strength of polymer resin grout with fly ash. *Applied Mechanics and Materials*, *789*, 38-42. https://www.scientific.net/AMM.789-790.38

Navaratnarajah, V. (1983). Splicing of reinforcement bars with epoxy joints. *International Journal of Adhesion and Adhesives*, *3*(2), 93-99. https://doi.org/10.1016/0143-7496(83)90023-4

Petrie, E. M. (2006). Epoxy adhesive formulations. https://cir.nii.ac.jp/crid/1130000796394975744

Raymond, J., & Sauntson, B. (1987). Resins and polymers for grouts, concrete and filled systems-A wide perspective. *In Proc 5th Int. Congress on Polymers in Concrete* (27-31).

Rebeiz, K. S., Rosett, J. W., & Craft, A. P. (1996). Strength properties of polyester mortar using PET and fly ash wastes. *Journal of Energy Engineering*, *122*(1), 10-20. https://doi.org/10.1061/(ASCE)0733-9402(1996)122:1(10)