Construction and Building Materials 24 (2010) 1821–1829

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Construction tolerances and design parameters for NSM FRP reinforcement in concrete beams

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ARTICLE INFO

Article history:
Received 9 July 2008
Received in revised form 15 March 2010
Accepted 1 April 2010
Available online 21 May 2010

Keywords:
Concrete
Construction tolerance
Fiber reinforced polymers
Finite element analysis
Near surface mounting

ABSTRACT

Aging infrastructure worldwide has made rapid means of repair and retrofitting a growing necessity. Fiber reinforced polymers (FRP) can provide a cost-effective and accelerated repair technique with near surface mounting (NSM) of pre-cured bars or strips in a bed of epoxy placed in pre-cut grooves. The performance of NSM FRP reinforcement depends on both geometric and mechanical properties of the system. Within the scope of this study, an experimental program was carried out to identify the effects of groove size tolerance on NSM FRP systems. Test results showed that the groove size tolerance up to ±22% does not affect the overall performance of such systems. The findings were also verified with a finite element model, which was then extended to study the effects of other geometric and physical parameters. Finally, a comprehensive database of test results available in the literature was compiled, and a comparative study was conducted on the geometric and material properties of the NSM FRP systems.

1. Introduction

Application of near surface mounted (NSM) steel rebars inserted into pre-cut grooves in concrete can be traced back to the repair of a deficient bridge in Sweden in the late 1940s [1]. However, the use of NSM fiber reinforced polymer (FRP) reinforcement with epoxy adhesive paste is quite new [2]. The NSM FRP application offers several advantages over external bonding (EB) of FRP: (a) the reinforcement can be anchored into adjacent members; (b) the members can be strengthened in their negative moment regions; (c) the members do not require as much surface preparation (e.g., grinding, treating cracks and voids) as in external bonding application; and (d) the procedure requires minimal installation time once the groove is cut [3]. Nevertheless, research on NSM FRP has been limited as compared to EB FRP; and design and construction guides are still lacking [4].

The effects of groove geometry on NSM FRP systems have been studied by various researchers. The most frequently studied parameters are shown in Fig. 1, where W is the groove width, H is the groove depth, w is the FRP strip width, h is the FRP strip height, d_b is the FRP bar diameter, d_e is the distance from the groove edge to the member surface, d_g is the clear spacing between the grooves, and d_s is the distance from the centroid of the FRP reinforcement to the centroid of the tension steel. Paretti and Nanni [3] suggested that the groove width (W) and depth (H) should be at least $1.5W$ and $3H$ for FRP strips, respectively, or $1.5d_b$ for FRP bars for both width and depth. De Lorenzis and Nanni [5] recommended that groove dimensions for the 10 and 13 mm diameter FRP bars be at least 19 and 25 mm, respectively.

Hassan and Rizkalla [6] proposed that the clear spacing between the grooves be at least twice the bar diameter, regardless of the groove width. They also suggested a minimum edge distance of four times the bar diameter to avoid excessive stress concentration near the edges. Using a finite element model, they further showed that the stresses in concrete decreased with the increasing groove width. The effect of epoxy type was also studied, but negligible differences in the ultimate loads were reported. In an earlier study by Hassan and Rizkalla [7], it was noted that larger groove widths would result in larger debonding loads due to the increase in the interfacial area between the epoxy and concrete. The debonding loads would also increase for concretes with higher compressive strengths.

Novidis and Pantazopoulou [8] observed an increase in the flexural strength for deeper grooves. Their study also showed that for the same area of NSM FRP reinforcement, flexural strength increases with the number of FRP strips, i.e., using smaller strips.

Testing specimens with different amounts of NSM FRP, Barros et al. [9] reported that strengthening efficacy, a measure of improved flexural strength, has an inverse relation with the FRP reinforcement ratio (ρ_f). Analyzing the available research data, they also reported that the ratio of the maximum to ultimate strains in FRP ($\varepsilon_{max}/\varepsilon_u$), increased with decreasing ρ_f and increasing d_g and d_e. Kotynia [10] reported that using high modulus NSM FRP increased the flexural strength but reduced the $\varepsilon_{max}/\varepsilon_u$ ratio.

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doi:10.1016/j.conbuildmat.2010.04.022

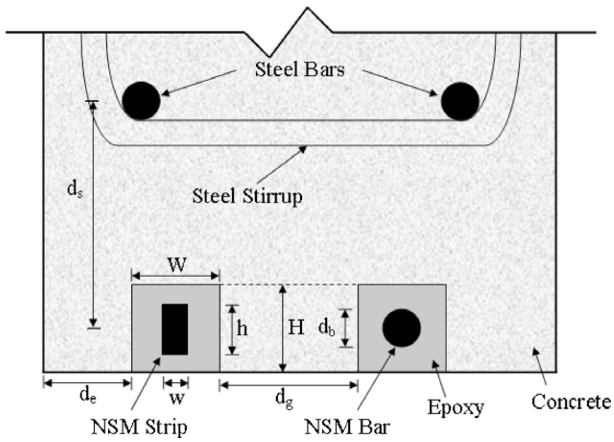

Fig. 1. NSM FRP and groove geometry.

Although there is significant research data on bond characteristics of NSM FRP systems, the effect of groove size tolerance on the overall structural performance of retrofitted beams has not yet been studied. This study focused on establishing construction thresholds for groove size tolerance, and to further investigate the effects of design parameters such as the multiple bars or strips, groove width and depth, concrete compressive strength, and the type of FRP and epoxy. The study included an experimental component on the NSM groove size tolerances, a finite element analysis of NSM FRP with an array of geometric and physical parameters; and a synthesis of test database compiled from the literature.

2. Experimental program

2.1. Test specimens

A total of twelve 2.1 m long beams with a clear flexural span of 2 m and a T-section were tested in three-point bending (see Fig. 2). Half of the beams were retrofitted with FRP strips and the other half with FRP bars. Longitudinal steel reinforcement consisted of 2 No. 10M bars in compression and 2 No. 16M bars in tension. Shear reinforcement included No. 10M stirrups at 127 mm on center. The total length of the FRP strips or bars used was 1715 mm.

2.2. Material properties

All specimens were cast using a single batch of ready mix delivered concrete with a compressive strength of 29.7 MPa measured from test cylinders. The yield strength of steel was 455 MPa. Average tensile modulus of elasticity and tensile strength of the epoxy paste were 3 GPa and 62 MPa, respectively, as reported by the manufacturer. Table 1 lists the geometric and material properties of carbon fiber reinforced polymer (CFRP) strips and bars utilized as NSM reinforcement.

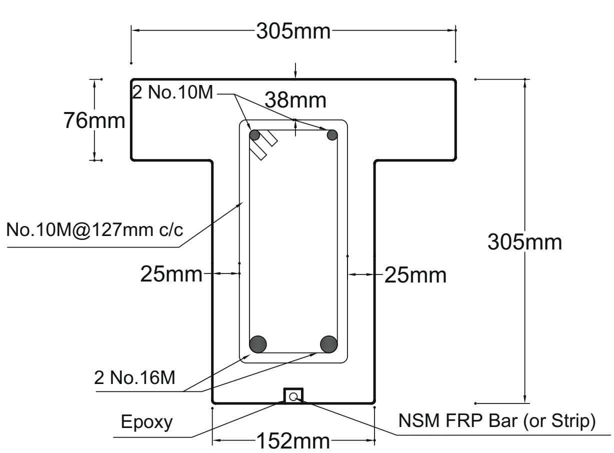

Fig. 2. Specimen cross section.

Table 1
Properties of NSM FRP reinforcement.

	CFRP strip	CFRP bar
Type	No. 5M	No. 9M
Diameter (mm)	–	9
Width (mm)	4.5	–
Depth (mm)	16	–
Tensile strength (MPa)	2068	2068
Tensile modulus (MPa)	124,100	124,100

Table 2
Test matrix for NSM grooves.

Reinforcement type	Groove depth (mm)	Groove width (mm)	Groove type	Number of identical specimens
NSM FRP strip	25	11	Undersized	2
	25	14	Control[a]	2
	25	17	Oversized	2
NSM FRP bar	11	11	Undersized	2
	14	14	Control[a]	2
	17	17	Oversized	2

[a] Design size.

2.3. Test matrix

Table 2 summarizes the test matrix for NSM FRP strips and bars consisting of control (i.e., design size), undersized and oversized grooves, with two identical specimens for each condition. Rectangular grooves were utilized for the strips, and square grooves for the bars. Undersized and oversized grooves were prepared with ±3 mm tolerance.

2.4. Specimen pre paration

Grooves of desired dimensions were cut end to end on the soffits of the beams using a diamond blade hand saw. A metallic guide was used to ensure the straightness and the accuracy of the groove size. Fig. 3 shows the NSM groove in one of the specimens, laid upside down.

Fig. 3. Typical NSM groove.