EFFECT OF STEEL FIBRES ON THE DEVELOPED STRESSES IN DEFORMED HEADED BARS

AL-TA'AN S.A. [1], RAHOMY S.S.M. [2]

Abstract

This investigation studied the effect of steel fibres on the developed stress in headed bars. One concrete mix is used with a weight proportions of (1:1.7:3:0.45;cement:sand:gravel and water cement ratio respectively) and gave a minimum cylinder strength of 37.5 MPa. The variables included three bars sizes (10, 12 and 16 mm), embedment depths(50, 55, 60, 65, 95 and 100 mm,) three plane dimensions of a 10 mm thick square steel head (20×20, 25×25 and 30×30 mm) welded to the bars, and the steel fibres volume percentage (0.4,0.8 and 1.2). The steel fibres were of the Harex type with irregular cross section, 16 mm long and an equivalent aspect ratio of 19.64. The test results showed that the developed stress in the bars increased with the embedment depth and with the steel fibres percentage considerably, while the used dimensions of the square steel head does not affect the steel stress significantly. The failure mode of the concrete specimens was sudden and brittle while that of the fibrous concrete specimens showed a gradual and ductile mode of failure.

Keywords: Embedment, fibres, headed reinforcement, pullout, stress

1. Introduction

Headed bars are bars with a steel plate (square, rectangular, circular or oval in shape) fixed to the discontinuous end of the bar by welding or threading. This will provide additional area to resist the tensile forces exerted on the bar and inhibit the tendency of the pull out process. The final aim of this process is to reduce the required development length or the splice length (lap splices) in tension for bars with relatively large diameters ending at the discontinuous ends of members, like beam-column joints where it is not possible to provide the required straight development length, even if a standard hook is provided.

In 1970 an experimental investigation is conducted [1] on 19 pull out tests for headed bars with diameters 35, 44 and 57 mm. The aim of the investigation was to replace hooks with steel heads. The embedment depths (h_{ef}) varied between 8 to 32 d_b and three ratios of the net head area to the area of the bar (A_{nh} / A_b = 0, 1.8 and 13) were used. The test results showed that when the embedment depth is small, the pull out force is carried by the head

[1]Al-TA'AN, S. A., Dept. of Civil Engg., Mosul University, Mosul, Iraq, +9647704819218, saad.altaan@yahoo.com

[2] RAHOMY,S.S.M., Dams Engg. And Water Resources Dept., Mosul University, Mosul, Iraq.

and the specimens with A_{nh} / A_b =1.8 gave results comparable to those carried by specimens with A_{nh} / A_b =13, which means that small bar heads can lead to yielding of the bar.

SINTEF Group [2] conducted tests on Friction-Welded Bar to assess the method of fixing the head to the bars. Two bars sizes were used, 19 and 25 mm with a ratio of $A_{nh} / A_b = 6$. Normal and light weight concretes were used with a compressive strength of 60 and 71MPa respectively and a yield strength f_y of the bars of 551 MPa. Direct tensile forces and bending moments were applied to the specimens, and all the specimens were failed through the bar head connection.

An experimental investigation was carried out at Kansas University [3] on headed bars at the discontinuous end of beams, to propose a design equation for the development length of headed bars. Three types of 25 mm diameter bars were used in the 70 beam specimens; bars without heads, bars with 180° hooks and bars with steel heads. The embedment depths were the same for all the bars and equal to 300 mm with a clear concrete covers of either 2 or $3d_b$. The test results showed that:

1. The headed bars carried a failure load equal to or greater than that carried by the hooked bars, and
2. Maximum failure load for the bars head is attained when the bars are debonded from concrete along its entire embedment length, and the clear concrete cover is $3d_b$ with transverse reinforcement provided.

In 1999 Vries et. al. [4] conducted pull out tests on headed bars to find the pull out capacity of such bars. The following variables were taken into account; bar diameter; the position of the bar in the specimen; embedment depth; concrete cover; spacing between bars; head dimensions and shape; transverse reinforcement and the bonded length of the bar to the surrounding concrete. The specimens failed either in concrete cone mode or rupture of bars. The test results showed that the headed bars could develop the yield stresses; increasing the bonded length will increase the developed stresses and decrease the slip; the transverse reinforcement did not increase significantly the developed stresses.

The test results of Reference [3] formed the basis of the ACI (318-11) equation [5] for the development length of headed bars in tension:

$$l_{dt} = 0.19 y_e . f_y / (\sqrt{f_c^{'} . d_b}) \tag{1}$$

y_e shall be taken as 1.2 for epoxy-coated reinforcement and 1.0 for other cases. Length l_{dt} shall not be less than the larger of $8d_b$ and 150 mm. The ACI Committee (318-11) restricted the use of heads to develop deformed bars in tension for the following conditions:

(a) Bar f_y shall not exceed 420 MPa;

(b) Bar size shall not exceed 35 mm diameter;

(c) Concrete shall be normal weight;
(d) Net bearing area of head shall not be less than $4A_b$;
(e) Clear cover for bar shall not be less than $2d_b$;
(f) Clear spacing between bars shall not be less than $4d_b$;and
(g) Concrete strength shall not exceed 40 MPa.

It is obvious that the tensile strength of concrete is one of the factors influencing the bond failure of reinforcing bars. Concrete is a brittle material with low tensile strength ranging between 8 to 14% of its compressive strength. The addition of steel fibers to concrete improves its tensile and flexural strength, ultimate strains, ductility, and fracture toughness [6]. Thus the behaviour and strength of headed bars embedded in fibrous concrete may be different from those embedded in normal concrete.

The aim of this investigation is to find out the influence of steel fibres on the tensile stresses developed in single headed bars.

2. Experimental Programme

2.1 Materials

The mix proportions (cement:sand:gravel) used were, 1:1.7:3.0 with a water cement ratio of 0.45. These proportions were chosen to give a nominal cylinder compressive strength of 35 MPa and a slump of about 100 mm. Ordinary Portland cement produced from Badoosh factory complying with the IQS: 1983 [7], medium river sand with a fineness modulus of 3.14 complying with BS:882 [8] , gravel with a maximum size of 12.5 mm complying with BS:882 [8] were used. Steel fibres of the Harex type is used, with a length of 16 mm and equivalent diameter of 0.815 mm; i.e., an aspect ratio of 19.64.

The pull-out specimens shown in Figure (1) were reinforced in the circumferential direction with 6 mm bars in the lower part and 8 mm bars for the upper part. In the longitudinal direction, 10 mm bars were used to arrest any possible cracks in the circumferential direction. Three bar sizes were used (10, 12 and 16 mm) and attached to the upper end of the pull-out specimens and 16 mm or 25 mm bar attached to the lower end of the pull-out specimens. The bar was inserted in a central hole of diameter equal to the bar diameter and was welded to the head [9]. The properties of the headed bars are shown in Table (1).

Tab. 1: Properties of the reinforcing bars

Bar Diameter (mm)	Yield Strength (MPa)	Tensile Strength (MPa)
10.0	440	710
12.0	468	702
16.0	399	714

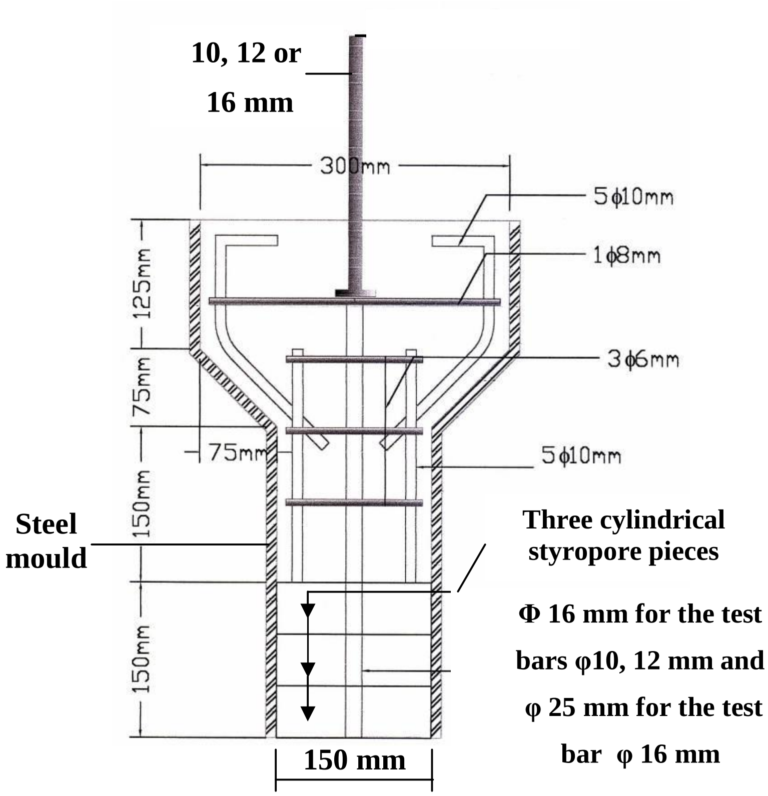


Fig. 1: Detail of the pull-out specimens

2.2 Specimens

Tables (2-4) show the dimensions of the heads for the three bar sizes. For each head and bar size four steel fibres percentage were used (0, 0.4, 0.8 and 1.2). The total number of the specimens is 76.

Tab. 2: Variables for the test bar 10 mm diameter

h_{ef} (mm)	50			55		
Head dimensions (mm)	20×20	25×25	30×30	20×20	25×25	30×30
V_f %	0, 0.4, 0.8 and 1.2 for each head dimension					

Tab. 3: Variables for the test bar 12 mm diameter

h_{ef} (mm)	55			60			65		
Head dim. (mm)	20×20	25×25	30×30	20×20	25×25	30×30	20×20	25×25	30×30
V_f %	0, 0.4, 0.8 and 1.2 for each head dimension								

Tab. 4: Variables for the test bar 16 mm diameter

h_{ef} (mm)	95		100	
Head dim. (mm)	25×25	30×30	25×25	30×30
V_f %	0, 0.4, 0.8 and 1.2 for each head dimension			

Testing Procedure

The specimens were fixed to the testing machine by attaching the (16 or 25 mm) bar to the fixed bottom part of the machine, and the tested bars (10, 12 or 16 mm) to the upper moving part of the universal testing machine. The pullout load was applied monotonically at a constant rate to prevent any dynamic effect during the test.

3. Results and Discussion

3.1 Influence of Fibres Volume Fraction

Table (5) shows the developed steel stresses at failure for the 10 mm diameter headed bar, it can be noticed that the developed steel stresses increased with the steel fibres volume for all the heads used. It can be seen also that the steel stresses increased with the embedment depth as shown by many other researchers [10,11]. Fig.(2) show that the measured steel stresses for the embedment depth h_{ef} = 50 mm exceeded the yield strength of the bar for all the head dimensions used.

Tab. 5: Experimental Steel Stresses for the Test Bar 10 mm Diameter

h_{ef} (mm)	50				55			
Head Dim. \ V_f %	0	0.4	0.8	1.2	0	0.4	0.8	1.2
20×20	470	625	703(SF)	681	610	644	707(SF)	696
25×25	570	623	673	673	588	717(SF)	712(SF)	713(SF)
30×30	507	610	702(SF)	697	649	699	693	717(SF)

SF Steel failure

Table (6) shows the developed steel stresses at failure for the 12 mm diameter headed bar, it can be noticed also that the developed steel stresses increased with the steel fibres volume for all the heads used. As shown for the previous bar diameter (10 mm) the steel stresses increased with the embedment depth. Fig.(3) shows that the measured steel stresses for the embedment depth h_{ef} = 60 mm exceeded the yield strength of the bar for all the head dimensions used. Stresses in bars with the other embedment depths also exceeded the yield strength except bars with embedment depth (h_{ef} = 55 mm, V_f =0 and 0.4%).

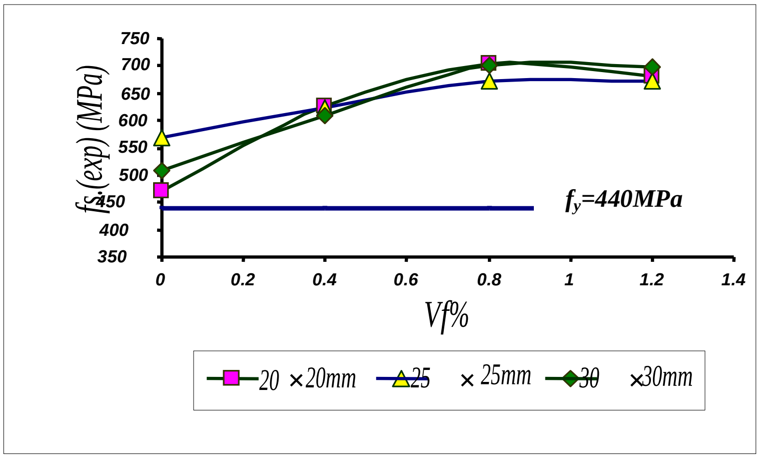


Figure 2: Variation of the steel stress with the fibres volume for bars with diameter =10 mm and h_{ef} = 50 mm

Tab. 6: Experimental Steel Stresses for the Test Bar 12 mm Diameter

h_{ef} (mm)	55				60				65			
V_f / Head Dim.	0	0.4	0.8	1.2	0	0.4	0.8	1.2	0	0.4	0.8	1.2
20×20	423	451	487	508	468	475	500	558	472	506	570	610
25×25	393	448	508	515	476	497	520	530	548	620	623	625
30×30	400	460	485	520	463	489	493	555	516	567	580	583

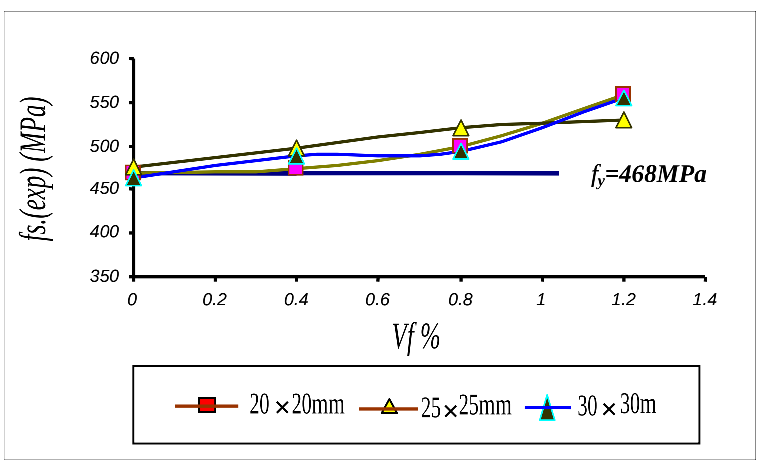


Fig. 3: Variation of the steel stress with the fibres volume for bars with diameter =12 mm and h_{ef} = 60 mm

Table (7) shows the developed steel stresses at failure for the 16 mm diameter headed bar, it can be noticed also that the developed steel stresses increased with the steel fibres volume for the two heads used. As shown for the previous bars (10 and 12 mm) the steel stresses increased with the embedment depth. Fig.(4) shows that the measured steel stresses for the embedment depth h_{ef} = 95 mm exceeded the yield strength of the bar for the two head dimensions used. Stresses in bars with the embedment depth (h_{ef} =100 mm) also exceeded the yield strength for all the fibres volume fractions.

Tab. 7: Experimental Steel Stresses for the Test Bar 16 mm Diameter

h_{ef} (mm)	95				100			
V_f / Head Dim.	0	0.4	0.8	1.2	0	0.4	0.8	1.2
25×25	406	411	423	472	421	458	482	485
30×30	431	436	453	475	414	453	480	487

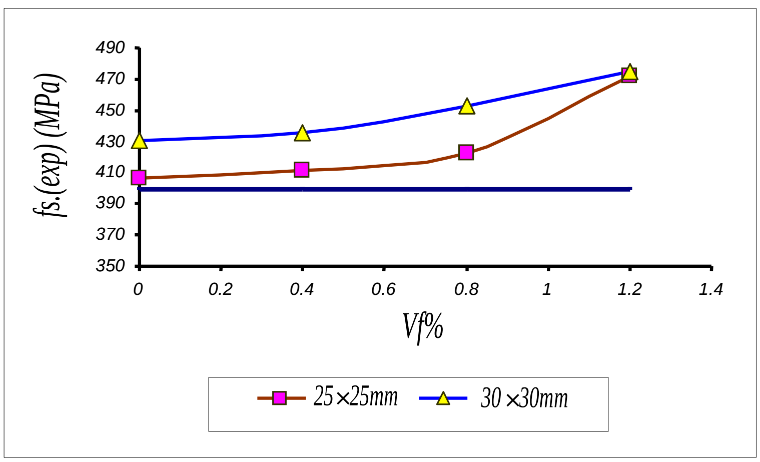


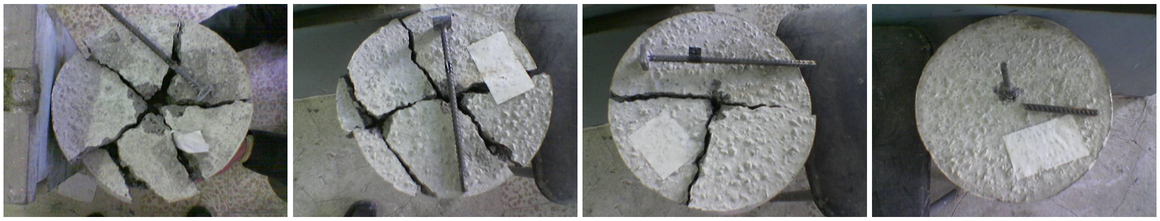
Fig. 4: Variation of the steel stress with the fibres volume for bars with diameter =16 mm and h_{ef} = 95 mm

3.2 Influence of Head Dimensions

Tables (5-7) show also the variation of the steel stresses with the head dimensions, the results show that there is no general trend between the head dimensions and the developed steel stresses. This is in agreement with the findings of references [1,12].

3.3 Modes of Failure

Figs. (5-7) show some typical failure modes for some of the specimens with the three bars diameter (10, 12 and 16 mm) and different volume fraction of steel fibres. The presence of steel fibres retain the integrity of the specimens and change the brittle mode of failure to a ductile one.



$V_f = 0.0$ | $V_f = 0.004$ | $V_f = 0.008$ | $V_f = 0.012$

Fig. 5 Failure modes for bars diameter = 10 mm, h_{ef} =55 mm and head 30×30 mm

$V_f = 0.0$ | $V_f = 0.004$ | $V_f = 0.008$ | $V_f = 0.012$

Fig. 6 Failure modes for bars diameter = 12 mm, h_{ef} = 65 mm and head 25×25 mm

$\mathbf{V}_f = 0.0$ | $\mathbf{V}_f = 0.004$ | $\mathbf{V}_f = 0.008$ | $\mathbf{V}_f = 0.012$

Fig. 7 Failure modes for bars diameter = 16 mm, h_{ef} = 100 mm and head 25×25 mm

4. Regression Analysis

A regression analysis is conducted on the experimental results for the headed bars embedded in steel fibrous concrete, so that the equation can be used for any bar diameter, embedment depth and steel fibres percentage. The steel stress considered as the dependent variable, and the independent variables are ($\sqrt{f_c'}$, h_{ef}, V_f, l_f, d_f, A_p and A_b). The ACI Code (318-11) equation [5] for the development length was considered as a reference for the analysis. The variables (h_{ef}, $\sqrt{f_c'}$, and A_b) were lumped in this form ($h_{ef}.\sqrt{f_c'}/A_b$) . The influence of the head dimensions relative to the bar cross-section area were simulated in this form ($1-A_p/A_b$), A_p = head area and A_b = bar cross-sectional area. The influence of the steel fibres was determined by trial and error method and the final equation was in the following form:

$$f_s = a_1 \frac{h_{ef} \cdot \sqrt{f_c^{'}}}{A_b} \frac{\left(1 + a_3 . V_f . l_f / d_f\right)}{\left(1 - a_2 . A_p / A_b\right)} \qquad (2)$$

The constants a_1 and a_2 were found from the regression analysis, and the constant a_3 was found by trial and error. Values ranging from 0.6 to 1.2 were tried and a value of 0.7 that gives the least deviation from the normal distribution (skewness a = -0.0022) was adopted. The equation is in the following form:

$$f_s = 140 \frac{h_{ef} \cdot \sqrt{f_c^{'}}}{A_b} \frac{\left(1 + 0.7 V_f . l_f / d_f\right)}{\left(1 - 0.0014 . A_p / A_b\right)} \qquad (3)$$

The Coefficient of correlation R^2=0.997, the average value of experimental / calculated value from the equation was 1.00 and a standard deviation of 0.06. Figure 8 shows the histogram for the experimental / predicted values of the steel stress. The Figure shows that about 68 out of the 76 values ($\approx$ 90%) are within 1 ± 0.07.

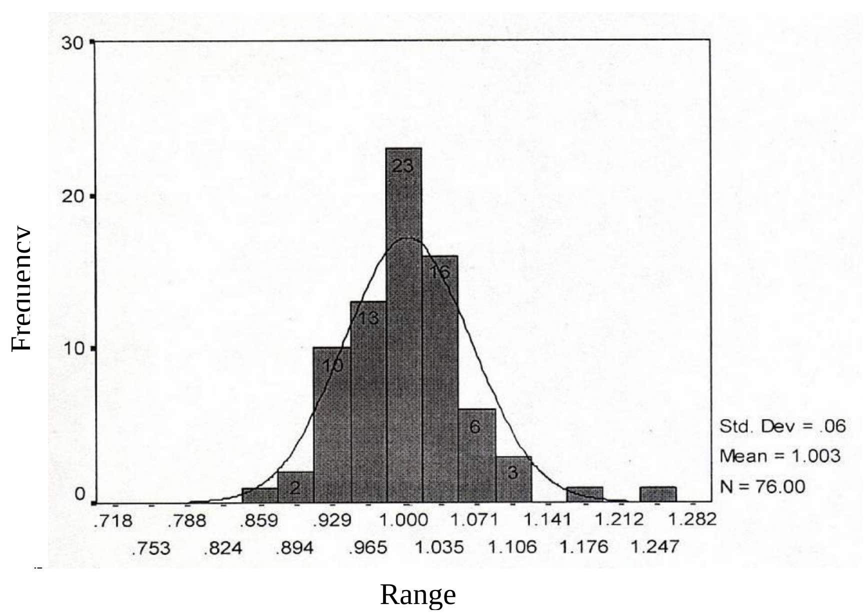


Fig. 8: Histogram of the Experimental / Predicted values of the Steel Stresses

5. Conclusions

The developed steel stresses in headed bars increased with the embedment depth and with the steel fibres percentage. For the heads dimensions used in this investigation, there was no general trend of its influence on the developed steel stresses. The presence of steel fibres retain the integrity of the tested specimens during failure and change the brittle mode of failure to a ductile one..

Experimental results on other bars sizes, effect of concrete cover, bars spacing and group of headed bars embedded in steel fibrous concrete are required to serve as a design guide.

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