Bonding of Coated and Uncoated Bars to Concrete with Different Types of Coarse Aggregates

By

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1-Abstract

The objective of this research is to study the effect of different types of coarse aggregates on the relative bond-slip behavior of coated and uncoated reinforcing bars. It is known that the application of coating to the surface of a reinforcing bar will decrease the bond capacity by preventing adhesion between the bar and the surrounding concrete, but our interest is to study this decreasing in bond strength with different types of coarse aggregates, concrete strength, and the surface condition and the diameter of reinforcing bars. Epoxy paint coating is applied to the bar to a thickness of around 0.2 mm. Two grades of concrete strength are used. Two types of surface condition of reinforcing bars are considered, the first is smooth surface bars with fy of 24 kg/mm^2, the second is deformed surface bars with fy of 36 kg/mm^2. The diameters of bars used in this research are 10, 13, and 16 mm. The bars are tested in 30 cm height and 15 cm diameter concrete cylinder using push in test.

The results include the bond strength and bond-slip behavior of specimens. The effect of the considered parameters on bond strength is discussed, and a comparison between the performance of coated and uncoated bars is included.

ملخص البحث

الغرض من البحث هو دراسة تأثير اختلاف الركام الكبير على التماسك بين الخرسانة و الاسياخ المدهونه و غير المدهونه و يشمل البحث على المتغيرات التاليه :

١- نوع الركام الكبير حيث تم استخدام ثلاثه أنواع من الركام الكبير وهى الزلط والدولوميت و البازلت •

٢- دهان الاسياخ بابيوكسى من عدمة •

٣- حالة سطح الاسياخ حيث تم استخدام أسياخ ملساء ذو أجهاد خضوع ٢,٤ طن/سم٢ و أسياخ ذو نتوءات ذو خضوع ٣,٦ طن/ سم٢

٤- أقطار حديد التسليح حيث تم استخدام ثلاثة أقطار لكل نوع من نوعى الحديد المستخدم •

٥- مقاومة الخرسانة للضغط حيث تم تصميم خرسانة لتعطى جهد كسر ٢٥٠ كجم/سم٢ و اخرى لتعطى جهد كسر ٣٥٠ كجم/سم٢

وقد تم دراسة المتغيرات السابق ذكرها على حمل التماسك وجهد التماسك و العلاقه بين حمل التماسك و الحركة النسبية بين أسياخ التسليح و الخرسانة •

CERM. VOL. (19) NO. (3) MAY, 1997 P.P. 346-361

2- Introduction and Background

The theory of reinforced concrete is based on stress transfer between the reinforced steel bars and the surrounding concrete. This transfer of load or stress is made possible by the resistance to relative motion or slippage between the concrete and the surface of the embedded steel bar. The resistance to slippage is known as bond or bond stress.

The use of epoxy coated bars has been steadily increasing as designers utilize bars to reduce or eliminate problems with structures in corrosive environments. However, surface texture of the coating is smoother than the mill-scale finish of ordinary reinforcement, and alters bond behavior of the bar.

Many studied has been reported the effect of the most important factors on bond behavior. Little attention has been paid to the influence of the type of coarse aggregate using in concrete surrounding reinforced bars. This is likely to be an important factor on friction between steel and concrete along the face of the bar which plays an important role in developing bond strength

3- Experimental Program

In the experimental program, 216 pushin specimens were tested in twelve series, according to the type of coarse aggregates used. concrete compressive strength, and where the reinforcing bar coated with epoxy paint or not. In each series the variables were the surface condition of reinforcing bar, and its diameter The detail of experimental program is shown in table (1). The concrete specimens tested were cylinders with 15 cm diameter by 30 cm long. The test result was, the average of the testing three specimens. The concrete compressive strength of each series were determined by testing three cubes (15 x 15 x 15 cm). Fig.(1) shows some of the tested specimens

4- Material used

Coarse aggregate

All the coarse aggregate used (gravel, basalt, hard crushed limestone (dolomite) were free harmful chemicals, and with nominal maximum size 20 mm The grading of gravel was complying with the Egyptian standard. The size of the crushed limestone and bazalt was ranging between 10 mm and 20 mm.

Fine aggregate

The fine aggregate used was siliceous sand. It was free from harmful materials to concrete. The grading of sand was complying with the Egyptian standards.

Cement

Ordinary Portland cement was used. All the properties of the cement used within the specifications

reinforcing bar

Normal mild and high grade steel bars with yield strength 2.7 and 3.8 t/cm^2 respectively were used

5- Concrete mix

Each type of coarse aggregate has two different mixes of concrete compressive strength 250 and 350 Kg/cm^2. The difference between two mixes was in the cement content, which was 350, 400 Kg per cubic meter of concrete. The water cement ratios were different. The fine aggregate to the coarse aggregate ratio was one to two .

6- Test setup and measurement

The pushin test was applied using a hydraulic testing machine of 200 ton capacity. The slip of reinforcing bars was measured using dial gauge. The dial gauge was fixed in a steel arm and touch the reinforcing bar on a point.

7- Test results and Discussion

The test results included, the ultimate load of bond tests, the bond strength, and the load slip curves. The results showed the effect of : coarse aggregate type, coating and uncoating of steel bars, steel bars surface and diameter, and concrete compressive strength on bond between concrete and steel bars. In the following paragraphs the test results will be explained and discussed.

7-1 Effect of coarse aggregate type on ultimate bond load

Tables (2,3) show the ultimate bond load for concrete compressive strength (f_{cu}) equal to 250 Kg/cm^2 and 350 Kg/cm^2 respectively . From table (2) and figs. (2,3) it is noticed that the ultimate load bond for concrete made by dolomite aggregate are higher than similar ultimate bond load for concrete made by gravel and bazalt. For specimens made with ribbed bars (High grade steel bars) the ultimate bond load for concrete (f_{cu} = 250 Kg/cm^2) made by using dolomite aggregate is higher by about 12% and 14% than those made by using gravel and bazalt respectively. For specimens made with smooth bars (Normal mild steel bars) the above ratios became 24% and 12% respectively. The above ratios showed that the bond between concrete made by using gravel and smooth bars is much lower. That can be refereed to the smooth surface of both gravel and steel bars . Table (3) and figs.(4,5) are similar to table (2) and figs. (2,3) but they are for concrete compressive strength (f_{cu}) equal to 350 Kg/cm^2 instead of 250 Kg/cm^2. The relations from table (2) and figs. (2,3) could be confirmed by results in table (3) and figs. (4,5) as follows. The ultimate bond load between concrete (f_{cu} = 350 Kg/cm^2) made by using dolomite aggregate and ribbed bars are higher by about 13% and 15 % than those made by using gravel and bazalt respectively. For smooth bars the above ratios became 23.5 % and 11% respectively.

7-2 Effect of surface condition of steel bars on ultimate bond load

It can be noticed from tables (2,3) and figs. (2,3,4,5) that the ultimate bond load between concrete and ribbed bars is higher than that ones between concrete and smooth bars. The ratio between ultimate bond load for concrete (f_{cu} = 250 Kg/cm^2) made by using dolomite aggregate with ribbed bars and that with smooth bars is 1.31. This ratio is 1.45 and 1.29 for concrete made by using gravel, and bazalt respectively, despite the smaller of the actual bar diameter of ribbed bars than the similar ones of smooth bars. The above ratios for concrete with compressive strength (f_{cu}) equal to 350 Kg/cm^2 became 1.33, 1.46, and 1.31 for concrete made by using dolomite, gravel, and bazalt respectively . From the results in tables (4,5), the ratios between the bond strength for concrete (f_{cu} = 250 Kg/cm^2) with ribbed bars and those for concrete with smooth bars are 1.425, 1.55, and 1.368 for concrete made by using dolomite, gravel, and bazalt respectively . For concrete with compressive strength (f_{cu}) equal to 350 Kg/cm^2 . The above ratios became 1.42, 1.506, and 1.366 respectively. It is noticed that these above six ratios for bond strength are higher than the similar ones for ultimate bond load because of the canceling of the effect of difference in bar diameters between ribbed bars and smooth bars.

7-3 Effect of coating and uncoating of steel bars on ultimate bond load.

Figs.(6,7,8,9) show a decrease in ultimate bond load due to the effect of coating. The decrease in ultimate bond load for specimens with ribbed bars due to coating of bars by epoxy resien(for concrete with f_{cu} equal to 250 Kg/^{cm2}) are 6.5 %, 4.5 %, and 4.8% for concrete made by using dolomite, gravel, and bazalt respectively . for smooth bars the decrease in ultimate bond load due to coating became more than the ratios mentioned before The decreasing ratios in case of smooth bars are 12%,9%, and 12.3% for concrete made with dolomite, gravel, and bazalt respectively . For concrete compressive strength (f_{cu}) equal to 350 Kg/cm^2 the decreasing ratios in ultimate bond lead due to coating bars are approximately similar to those ones for concrete compressive strength equal to 250 Kg/cm^2 . For ribbed bars the decreasing ratios are 5.7%, 2 %, and 3.8 % for concrete (f_{cu} = 350 Kg/cm^2) made by using dolomite, gravel, and bazalt . For smooth bars the decreasing ratios are 10.6 %- 8.6 %, and 11.6 % for dolomite, gravel. and bazalt .

7-4 Effect of concrete compressive strength (f_{cu}) on bond strength

As expected, the increase in concrete compressive strength (f_{cu}) cause an increase in bond strength for all tested specimens as shown in tables (4,5) and figs. (10,11) . The increase in concrete compressive strength (f_{cu}) from 250 Kg/cm^2 to 350 Kg/cm^2 i.e. by about 40% cause an increase in bond strength,for concrete with ribbed bars, equal to 19 %, 21%, and 17.3 % for concrete made by using dolomite, gravel, and bazalt respectively . For concrete with smooth bars the above ratios became 16.7 %, 21 %, and 20.8 % . This means that an increase in concrete compressive strength (f_{cu}) by 40 % cause an average increase in bond strength equal to 19.3 % for all types of specimens .

7-5 Load-slip relations

Load-slip relation are plotted in curves Figs. (12.13, 14) show the load-slip curves for different types of coarse aggregates. For all types of concrete aggregates, it can be noticed from these figs. that, at the same load level, the slip decreases with the increase of bar diameter for the same type of steel. Also the slip for smooth bars is higher than the similar ones for ribbed bars. The figs. show also that the rate of excess in slip increases with the increase of load level. The same relations are founded for coated bars. Figs. (15,16,17) are examples for showing the effect of coating steel bars on the load-slip relations. The figs. show that the slip for coated bars is higher than the similar ones for uncoated bars at the same load level. This is due to the decreasing of bond between concrete and steel bars due to the presence of coating. The curves for concrete made by using bazalt aggregate are not plotted in figs. (15,16,17) because they are generally similar to the curves for concrete with gravel aggregates. The load-slip curves for smooth bars for coated and uncoated bars are similar to those in figs.(15,16,17) for ribbed bars but of course with higher values of slip.

8- Conclusion

Based on the experimental results and for types of concrete, steel, and coating used, the following conclusions could be suggested :

- The bond loads, for concrete (f_{cu} = 250 Kg/cm^2) with dolomite aggregate, and for ribbed bars, are higher than those with gravel and bazalt by 12 % and 14 % respectively for smooth bars the above ratios are 24 % and 12%.
- The coating for ribbed bars with epoxy resien for concrete (f_{cu} = 250 Kg/cm^2) with dolomite, gravel, and bazalt causes a loss in bond by 6.5 %, 4.5 %, and 4.8 % respectively. For smooth bars the above ratios are 12 %, 9 %, and 12.3 %.
- The use of ribbed bars instead of smooth bars causes an increase in bond strength. For concrete (f_{cu} = 250 Kg/cm^2) the ratios of excess in bond strength for concrete with dolomite, gravel, and bazalt are 42.5 %, 55 %, and 36.8 % respectively.
- The variation of concrete compressive strength from f_{cu} = 250 Kg/cm^2 to f_{cu}= 350 Kg/cm^2 i.e. increasing f_{cu} by 40 % cause an average increase in bond strength by 19.3 %.
- The coating of steel bars by epoxy resien causes an increase in slip between concrete and steel bars.

9- References

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3- Cairns, J., and Abdullah, R ., " Fundamental Tests on the Effect of an Epoxy Coating on Bond Strength ", ACI Material Journal, V. 91, No.4, July-Aug.(1994).

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Table (1) Experimental Program

Series	Coasrse aggregate	coating	f_{cu} kg/cm^2	Nominal bar diameter mm	Surface condtion
A	Dolomite	coated	250	10&13&16	Smooth & Ribbed
B		uncoated			
H	Gravel	coated			
O		uncoated			
M	Bazalt	coated			
N		uncoated			
G	Dolomite	coated	350		
L		uncoated			
D	Gravel	coated			
K		uncoated			
C	Bazalt	coated			
E		uncoated			

actual bar diameters are 10,12.25, 16 mm for smooth bars (N.M.S.) and 10, 11.3, 15 mm for ribbed bars (H.G.S)

Table (2) Ultimate load (ton) of Bond tests for specimnes with concrete compressive strength (f_{cu}) equal to 250 kg/cm^2

Nominal bar diametter (mm)	Bazalt		Gravel		Dolomite	
	Ultimae bond Load P_u (ton)					
	N	M*	O	H*	B	A*
10Φ H.G.S.	6.99	6.82	6.94	6.8	7.59	7.21
10Φ N.M.S.	5.46	4.68	4.88	4.30	6.00	5.39
13Φ H.G.S.	8.30	7.82	8.45	8.10	9.71	8.73
13Φ N.M.S.	6.48	5.59	5.73	5.28	7.14	6.57
16Φ H.G.S.	9.63	9.33	10.16	9.70	11.78	11.30
16Φ N.M.S.	8.63	7.87	7.56	7.05	9.88	8.24

H.G.S : High grade steel (ribbed surface)
N.M.S : Normal mild steel (smooth surface)
* Coated

Table (3) Ultimate load (ton) of Bond tests for specimnes with concrete compressive strength (f_{cu}) equal to 350 kg/cm^2

Nominal bar diametter (mm)	Bazalt		Gravel		Dolomite	
	Ultimae bond Load P_u (ton)					
	E	C*	K	D*	L	G*
10Φ H.G.S.	7.95	7.85	8.21	8.09	9.42	9.26
10Φ N.M.S.	6.42	5.52	5.58	4.93	7.503	6.32
13Φ H.G.S.	10.27	9.42	9.845	9.626	11.27	10.213
13Φ N.M.S.	7.53	6.51	6.76	6.246	8.265	7.67
16Φ H.G.S.	11.21	11.015	11.625	11.336	13.617	12.83
16Φ N.M.S.	10.19	9.455	9.05	8.46	10.68	9.746

H.G.S : High grade steel (ribbed surface)
N.M.S : Normal mild steel (smooth surface)
* Coated

Table (4) Bond strength (kg/cm^2) for specimnes with concrete compressive strength (f_{cu}) equal to 250 kg/cm^2

Nominal bar diametter (mm)	Bazalt		Gravel		Dolomite	
	Ultimae bond Strength f_{bu} (kg/cm^2)					
	N	M*	O	H*	B	A*
10Φ H.G.S.	72.4	73.6	72.1	72.1	80.5	76.5
10Φ N.M.S.	55.7	47.8	49.8	43.9	61.2	5.5
13Φ H.G.S.	77.9	73.5	79.4	76.2	91.2	8.2
13Φ N.M.S.	56.1	48.3	49.6	45.7	61.8	56.9
16Φ H.G.S.	68.1	6.6	71.8	68.6	83.3	79.7
16Φ N.M.S.	57.2	52.1	50.1	46.7	65.5	54.6

actual bar diameters are 10,12.25, 16 mm for smooth bars (N.M.S) and 10, 11.3, 15 mm for ribbed bars (H.G.S)
* Coated

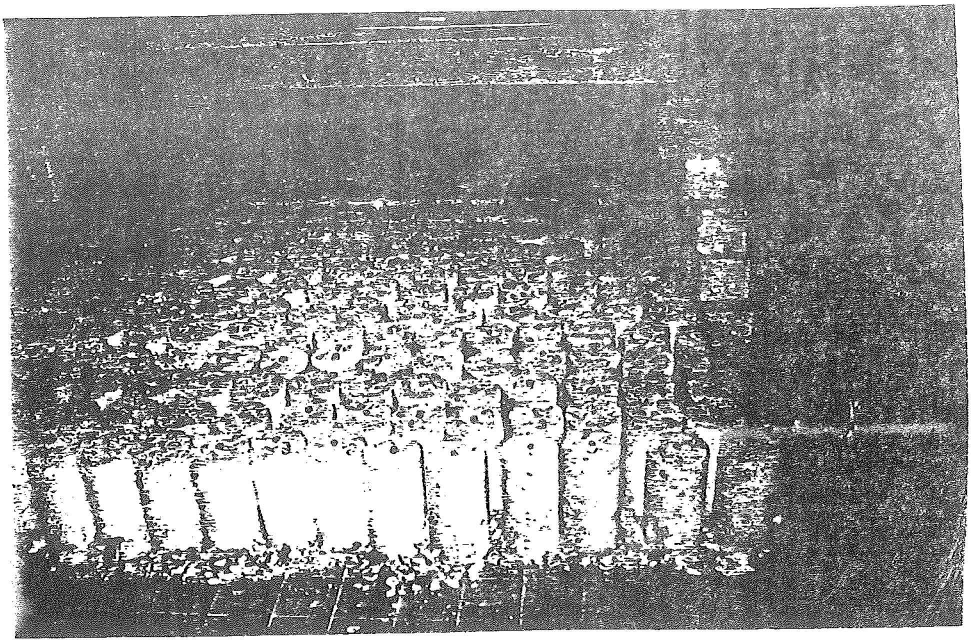
Table (5) Bond strength (kg/cm^2) for specimnes with concrete compressive strength (f_{cu}) equal to 350 kg/cm^2

Nominal bar diametter (mm)	Bazalt		Gravel		Dolomite	
	Ultimae bond Strength f_{bu} (kg/cm^2)					
	E	C*	K	D*	L	G*
10Φ H.G.S.	84.4	83.3	87.1	85.8	99.9	98.3
10Φ N.M.S.	65.5	56.3	56.9	50.3	76.5	64.5
13Φ H.G.S	96.4	88.5	92.5	90.4	105.8	95.9
13Φ N.M.S	65.2	56.4	58.6	54.1	71.6	66.4
16Φ H.G.S	79.3	77.9	82.2	80.2	96.3	90.8
16Φ N.M.S	67.6	62.7	60.0	56.1	70.8	64.6

actual bar diameters are 10,12.25, 16 mm for smooth bars (N.M.S) and 10, 11.3. 15 mm for ribbed bars (H.G.S)

* Coated

Fig.(1) some of the tested specimens .



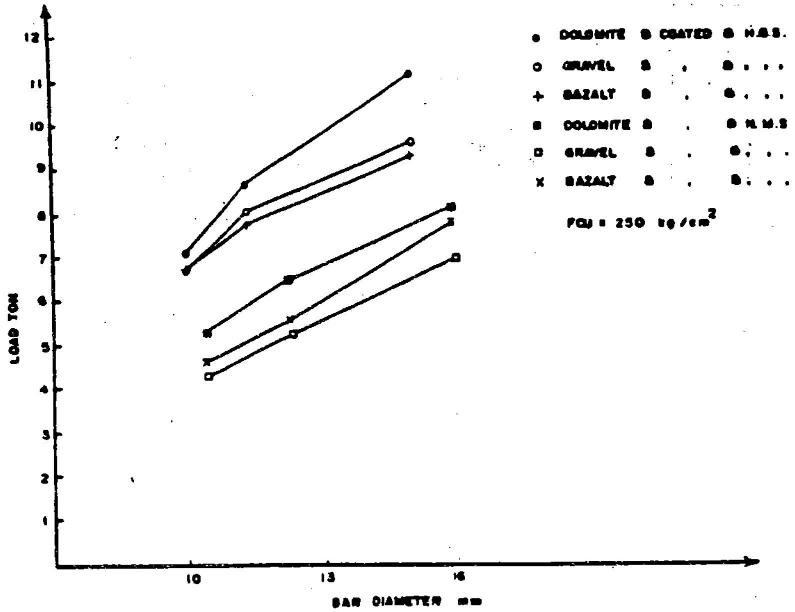


FIG. (2) : EFFECT OF CONCRETE COARSE AGGREGATE ON BOND LOAD FOR COATED BARS (RIBBED AND SMOOTH)

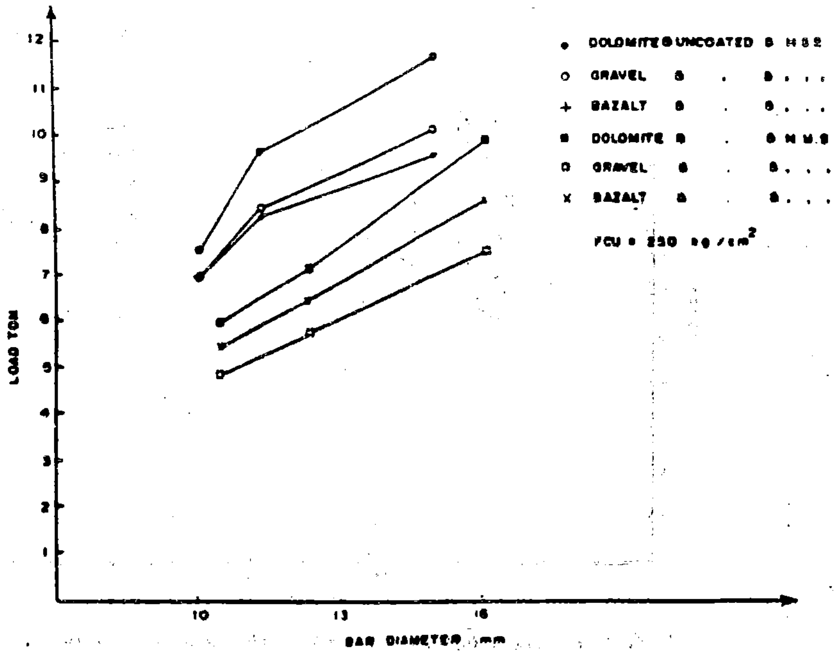


FIG. (3) : EFFECT OF CONCRETE COARSE AGGREGATE ON BOND LOAD FOR UNCOATED BARS (RIBBED AND SMOOTH)

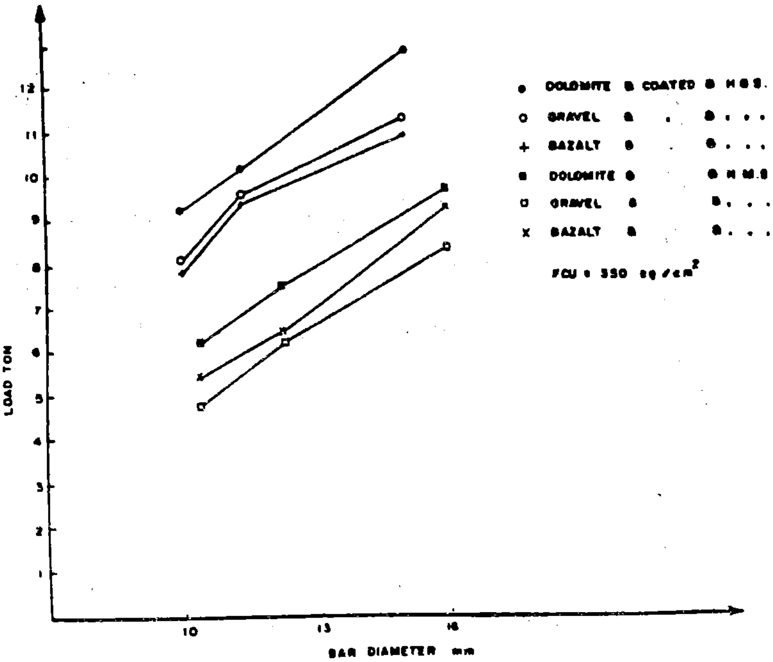


FIG. (4) EFFECT OF CONCRETE COARSE AGGREGATE ON BOND LOAD FOR COATED BARS (RIBBED AND SMOOTH)

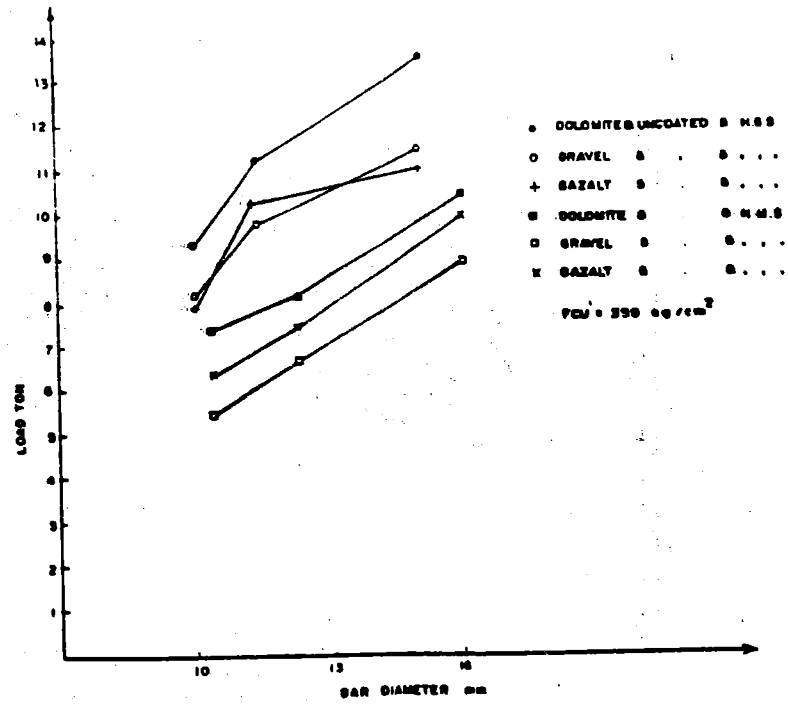


FIG. (5) : EFFECT OF CONCRETE COARSE AGGREGATE ON BOND LOAD FOR UNCOATED BARS (RIBBED AND SMOOTH)

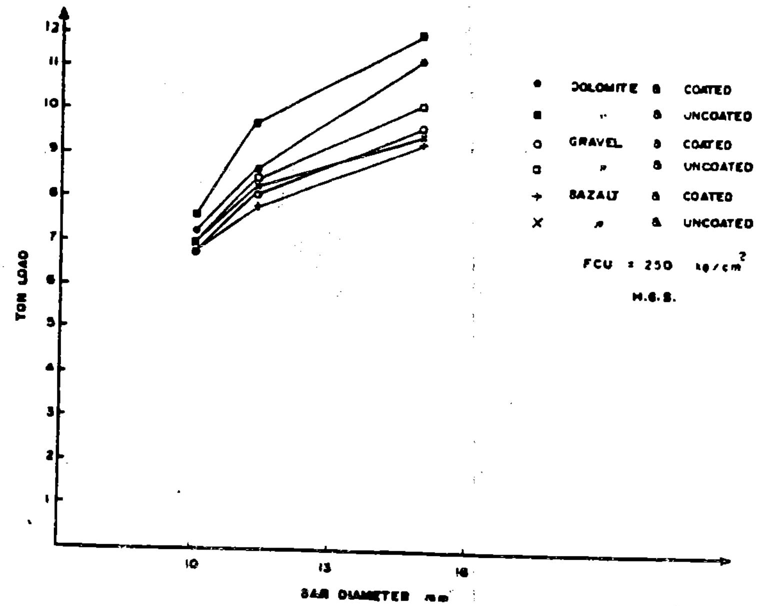


FIG.(6) : EFFECT OF COATED AND UNCOATED H.G.S. BARS (RIBBED) ON BOND LOAD FOR CONCRETE WITH DIFFERENT TYPES OF COARSE AGGREGATE

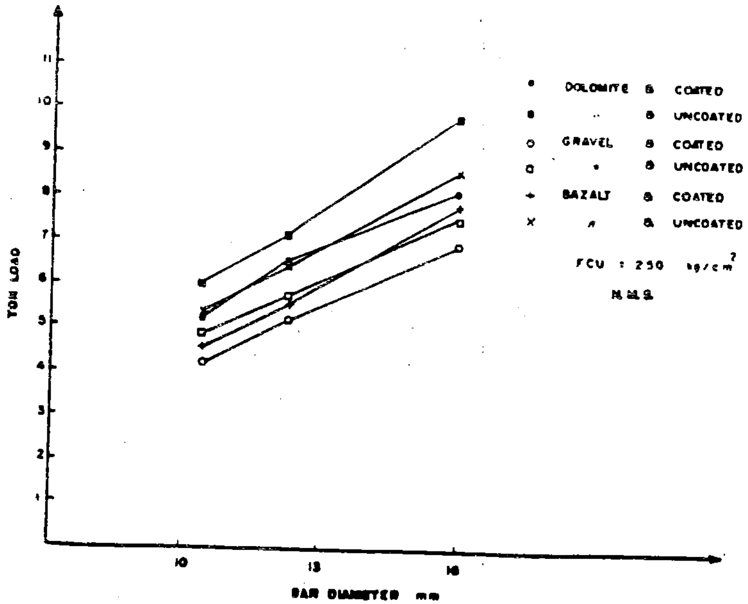


FIG.(7) : EFFECT OF COATED AND UNCOATED N.M.S. BARS (SMOOTH) ON BOND LOAD FOR CONCRETE WITH DIFFERENT TYPES OF COARSE AGGREGATE

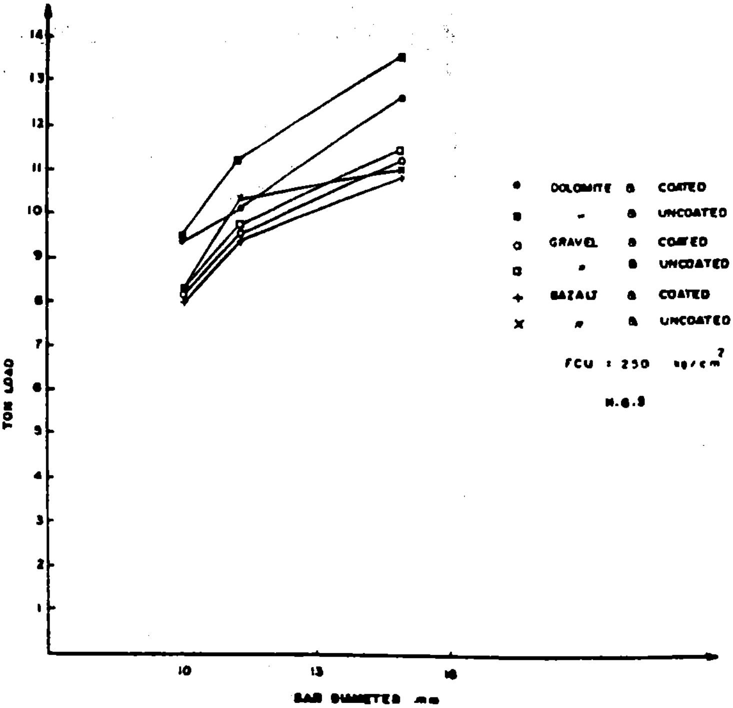


FIG.(8) : EFFECT OF COATED AND UNCOATED H.H.S. BARS (RIBBED) ON BOND LOAD FOR CONCRETE WITH DIFFERENT TYPES OF COARSE AGGREGATE

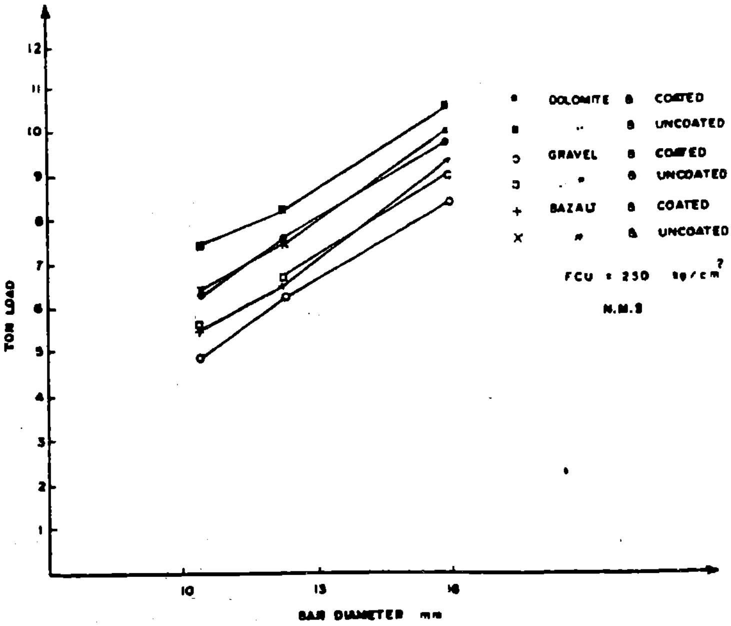


FIG.(9) : EFFECT OF COATED AND UNCOATED N.M.S BARS (SMOOTH) ON BOND LOAD FOR CONCRETE WITH DIFFERENT TYPES OF COARSE AGGREGATE

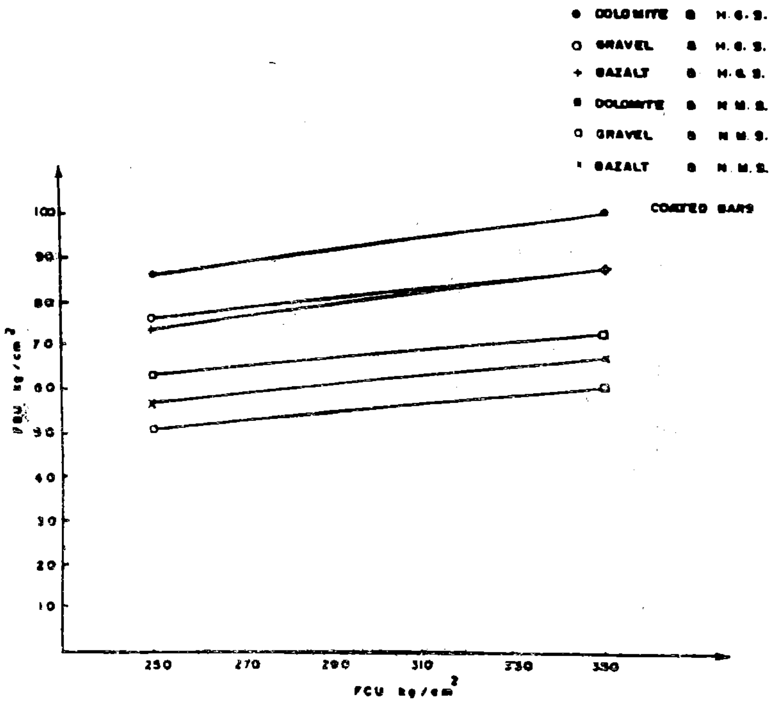


FIG.(10): EFFECT OF CONCRETE COMPRESSIVE STRENGTH (FCU) ON BOND STRENGTH (FBU) FOR CONCRETE WITH DIFFERENT TYPES OF COARSE AGGREGATE AND WITH COATED BARS

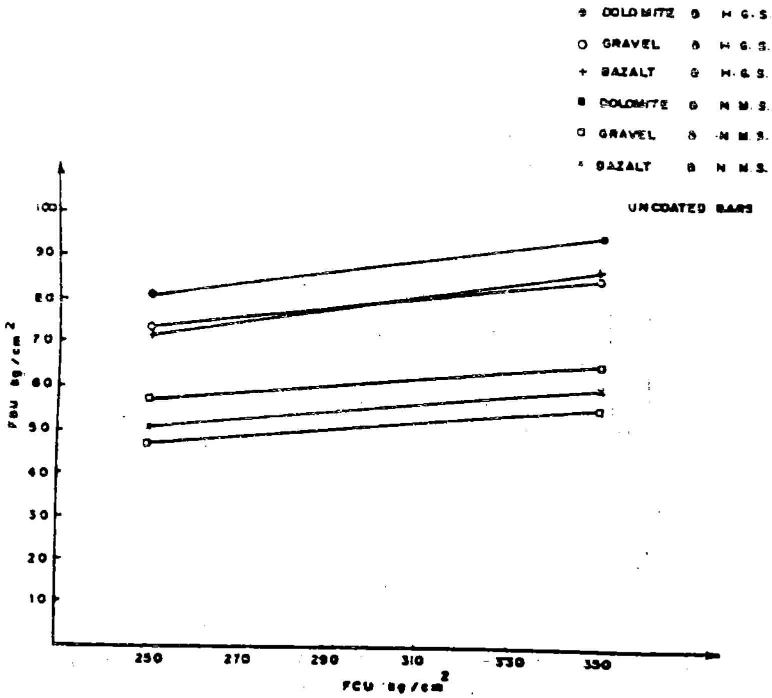


FIG.(11): EFFECT OF CONCRETE COMPRESSIVE STRENGTH (FCU) ON BOND STRENGTH (FBU) FOR CONCRETE WITH DIFFERENT TYPES OF COARSE AGGREGATE AND WITH UNCOATED BARS

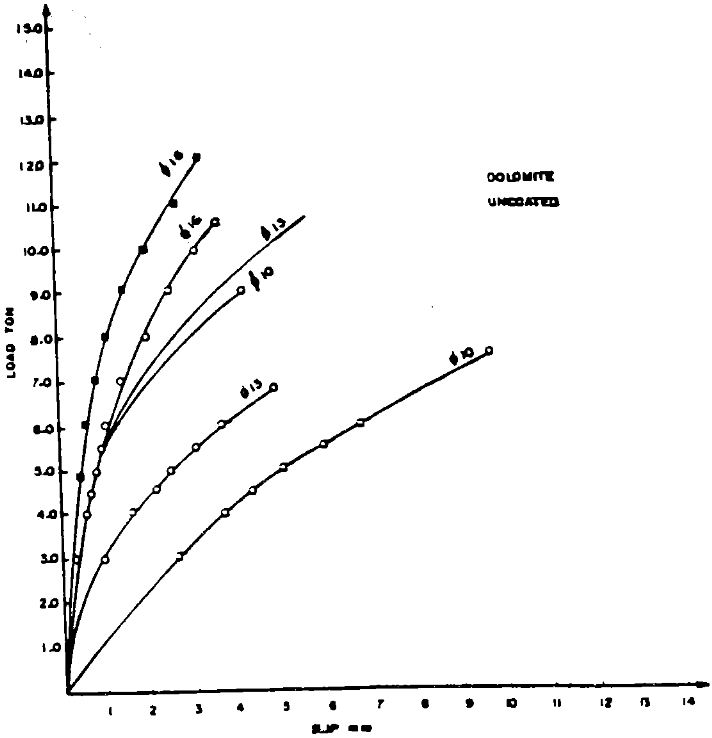


FIG. (12) : LOAD - SLIP CURVES FOR CONCRETE WITH DOLOMITE AGGREGATE AND UNCOATED BARS

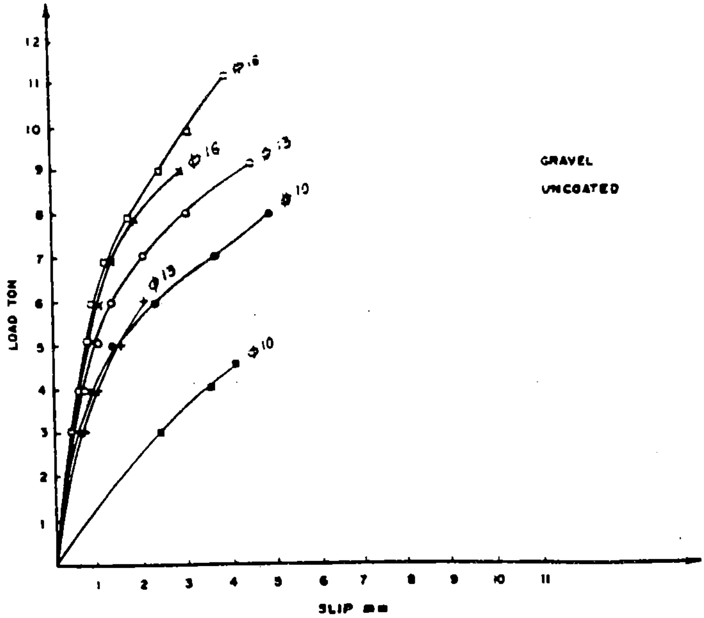


FIG. (13) : LOAD - SLIP CURVES FOR CONCRETE WITH GRAVEL AGGREGATE AND UNCOATED BARS

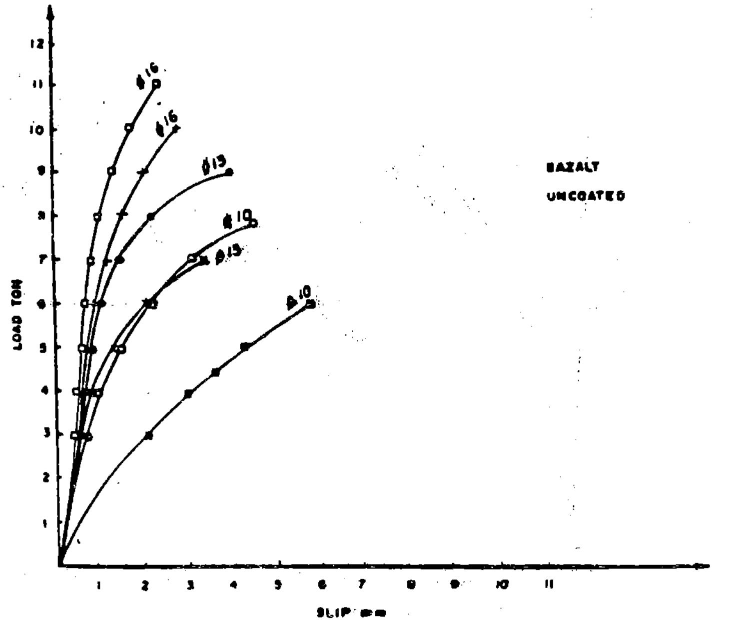


FIG.(14) : LOAD-SLIP CURVES FOR CONCRETE WITH BAZALT AGGREGATE AND UNCOATED BARS

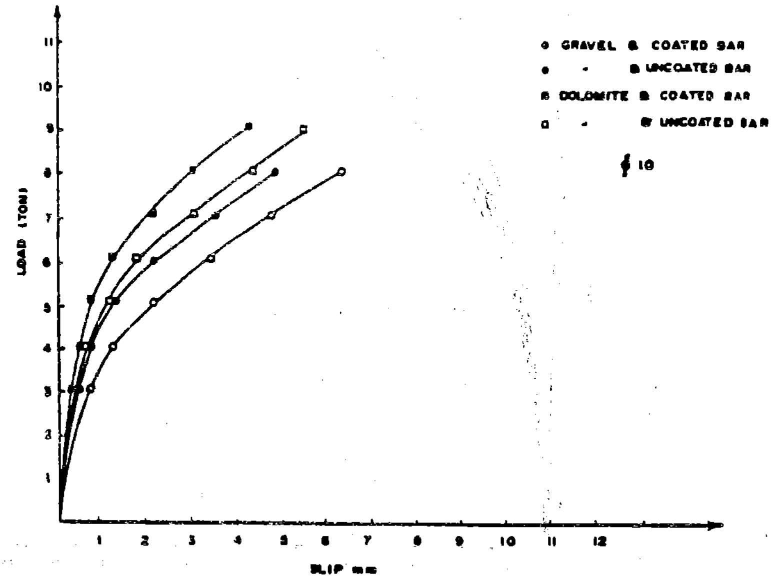


FIG.(15) : LOAD - SLIP CURVES FOR COATED AND UNCOATED STEEL WITH BAR DIAMETER (ϕ) EQUAL TO 10 mm

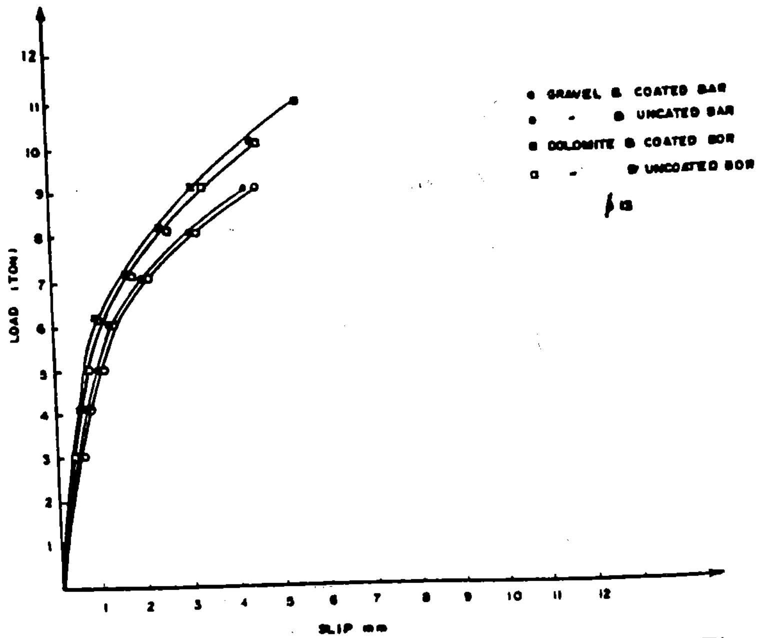


FIG.(16) : LOAD - SLIP CURVES FOR COATED AND UNCOATED STEEL WITH BAR DIAMETER (ϕ) EQUAL TO 16mm

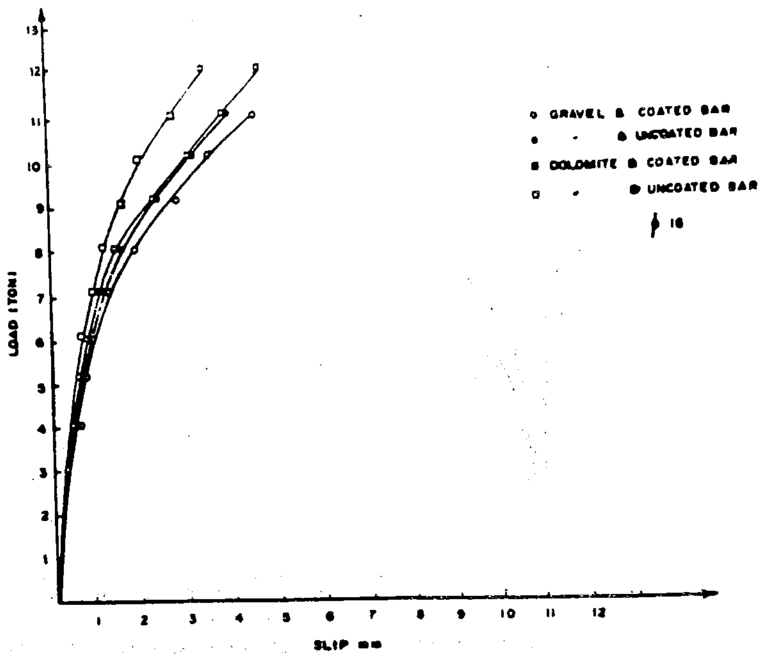


FIG.(17) : LOAD - SLIP CURVES FOR COATED AND UNCOAТED STEEL WITH BAR DIAMETER (ϕ) EQUAL TO 16 mm