STRUCTURAL ENGINEERING CHARACTERISTICS OF LOCALLY AVAILABLE STEEL REINFORCING BARS IN NIGERIA

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ABSTRACT

Investigation was carried on the locally available (Locally manufactured and imported) high yield steel bars of different diameters in Nigeria. The investigation involved the determination of their chemical constituents, mechanical characteristics as well as their behaviour in concrete beams. The steel specimens were tested in their original state, without machining.

The results showed that the imported high yield steel bars contained higher values of ferrous and carbon contents than the corresponding locally produced ones, thus resulting in higher yield and ultimate strength as well as higher transverse load bearing capacityof concrete beams, reinforced with them. The locally-produced steel bars behaved like mild steel in terms of the elongation while their yield stresses were very low, ranging between 63.76 to 204 N/mm^2. The behaviour of the reinforcing bars in concrete was consistent with their initial chemical composition and stress-strain characteristics.

It is recommended that in design, only high yield imported bars with diameter not less than 16mm should be used for structural concrete works while the yield stress should be around 280-300 N/mm^2. The locally manufactured high yield reinforcing bars would only be used for minor structural works. It is also recommended that samples of proposed steel bars should be tested prior to their use.

KEYWORDS: *Steel Reinforcing Bars, Locally Available Chemical constituents, Mechanical characteristics, Beams, Deflection*

1.0 INTRODUCTION

Some of the problems associated with steel production in Nigeria are high cost of operation, traceable largely to multiple taxes and levies as well as infrastructure inadequacies. Persistent shortage of fuel and fuel petroleum products had a negative impact on the manufacturing operations, resulting into high cost of production.

In Nigeria, there are two major steel producing companies - Delta Steel Company, Aladja in Delta state and Ajaokuta Steel Company, Ajaokuta in Kogi State. They produce steel from raw materials (iron ore) either as finished product or steel billets. The semi-finished products (steel billets) served as major raw materials for the three inland rolling mills located at Oshogbo (Osun State), Jos (Plateau State) and Katsina (Katsina State). The operations of these rolling mills were constrained due to inadequate inputs from the two major steel companies. There are other privately owned mini-mills, which depended partly on billets and large profiles of semi-finished products, obtained locally or imported. Some of them have small electric furnaces to produce liquid steel and then rolled to different profiles, mainly for local consumption. Examples are the Continental Iron And Steel Company (CISCO), Ikeja; Major Steel Company, Ikorodu, Lagos State; Asiatic Mandarin, Ikeja; Oro Steels Company, Oro, Kwara State; Qua Steels Company, Eket, Akwa Ibom State; Union Steel, Oro Kwara State.

Apart from the local production, large percentage of the available reinforcing steel is imported by organized private sector and multi-national construction companies from countries like Ukraine, Brazil, Libya, Russia, to supplement the local production. In conclusion, it can be said that there are various types of steel reinforcing bars in the Nigeria market both locally manufactured and imported. They are of varying unstandard sizes and these should be subjected to various tests to determine their structural engineering characteristics.

Akpan and Letcha (2) assessed the strength behaviour of locally manufactured reinforcing steel bars subjected to elevated temperature. They observed that it took about two hours in standard fire test to attain a temperature up to 600°C and concluded that mild reinforcing steel bars were more strength resistant than high yield steel if subjected to temperature of about 600°C and above. Ibanga and Ette (3) worked on the deep- drawing performance and structure properties of Nigerian produced mild steel. The results showed that a significant difference existed in the compositional characteristics of the locally produced steel rods compared to standard specification of mild steels for wire drawing application. The carbon content of the steel from Delta Steel Rolling Mill was found to be higher than the requirement of the standard. Although, the micro structural analysis of the local steel revealed decarburization and gain growth during process annealing, the ductility of the mild steel was found to be within an acceptance arrange for mild_steel. Inegbenebor (4) also worked on quality of steel bars produced in Nigeria when subjected to hear treatment while Grey et al (5) investigated the effect of heat treatment on torsional strength of mild steel weld joints.

Ajayi (6), based on the yield and elongation tests carried out on locally available steel for more than 10 years, observed that out of 718 No. Bars of varying diameters, only 31% complied with the expected hot rolled tensile steel bar requirements while 23% met the requirements for mild steel. He concluded that the test results failed to meet the requirements of the British Standard (7) which specified a minimum yield stress of 460 N/mm^2 with minimum elongation of 14% for hot rolled high yield steel bars or minimum yield stress of 250 N/mm^2 with minimum elongation of 22% for hot rolled mild steel bars. Without investigation into the causes of low yield stress of locally available reinforcing bars, Ajayi recommended the use of a low yield stress of 300-350N/mm^2 with 14% minimum elongation at rupture and an ultimate tensile strength of 110-130% of yield stress for structural design in Nigeria. His work did not consider the load-deformation pattern of the tested specimens or their chemical contents and his conclusion was based on the yield, and ultimate failure loads.

Imoisu Benos (8) investigated the stress-strain characteristics of reinforcing steels produced from Delta Steel Company, Aladja, Nigeria. His test results indicated that the high yield steel bars with higher amount of Carbon and Manganese possessed higher strength, less ductile than the mild steel bars. He concluded that the strength of all grades of reinforcing bars in the Nigerian market compared favourably well with the National Standard. This ascertion, however, required further investigation as this was based on results of samples obtained from only one source- Delta Steel Company. Apart from the fact that the steel samples were machined before being tested, which was not in accordance with the specification of the British Standard, BS 4449.

This present study examined the quality of reinforcing steel bars generally available in Nigeria, both locally produced as well as imported ones. So far little or no information has been obtained on the chemical and strength properties of these steel bars. Further, unstandardized sizes of reinforcing bars such as 9mm, 11mm, 14mm, 18mm are also available in the market. Effect of such steel reinforcing bars in concrete beams will also be investigated.

2.0 EXPERIMENTAL PROCEDURE

For the investigation, 3No. each of 12mm, 16mm and 20mm diameter of locally produced and imported high yield reinforcing bars were obtained from the distributors/marketers. A total of 18No samples were tested. The tests involved the chemical and mechanical analysis as well as performance of flexural tests on reinforced concrete beams, using the different reinforcing bars. For the determination of the chemical composition of the reinforcing bars, direct optical emission spectrometer was used. The spectrometer was first standardized using the steel reinforcement. The cutting disc was used to obtain 5mm thick bar, then the sample was grinded and polished before being taken to the spectrometer for sparking. The sample was placed in the chamber in such a way as to have contract with the "sparking pin"(electrode). The machine was then switched on and a sparking sound heard after 3-5 seconds, which determined the process. During the sparking, the characteristics radiations emitted by electrical discharge, containing vapour from the sample were dispersed into a spectrum and directed on to photo–multipliers, which measured their intensity, The results were displaced on the host computer, attached to the spectrometer. For the mechanical and deformation characteristics of the reinforcing bars, universal testing machine was used. For each bar a standard length of 60cm was considered while the gauge length was 5 times the diameter of the bar, Each steel rod was fixed into the jaws of the testing machine so that the two centre punched marks could be accessed.

Firm joint callipers and vernire callipers were used for measuring the distances between the punched marks. For each 2 tons increment in the tensile load, the distances were measured and recorded. The steel rods were tested to failure, while the yield point was observed.

In order to determine the effect of the local available steel reinforcement on the flexural capacity of beams, a total of 12No beams of 150mmx150mmx1500mm were cast. A design mix of 1: 2: 4 (cement: sand: granite) by weight with a water /cement ratio of 0.55 was adopted. For each beam 2No. of each type and size of reinforcing steel were used in the tension zone (bottom) while 2No.12mm bars were introduced as hanging bars (top) in all the beams. Shear reinforcements of 10mm diameter high yield bars at 80mm centre- to -centre were provided. The beams were tested, at the age of 28days on a simply supported span of 1350mm under symmetrical two–point loading, using the Avery universal testing machine. Dial gauge was placed at the central point on the underside of the beam. During the testing, development of cracks and central deflection for various load increments were observed for each beam.

3.0 RESULTS AND DISCUSSION

3.1 Chemical Analysis of the Reinforcing Steel Bars.

The results obtained from the chemical constituents test on the high yield steel samples were shown in Table 3.1. The most important and influential element in reinforcing steel is Carbon (C), apart from the main Ferrous element (Fe). In all cases, the imported high yield steel bars contained higher values of the ferrous and carbon than the corresponding local high yield steel bars. The locally produced 12mm diameter steel bars contained 0.166% of carbon, which was less than the minimum permissible of 0.25% (7). This result implied that the12mm diameter (local) would have reduced yield and ultimate strength while the ductility and weldability might increase. The 16mm diameter steel (both local and imported) contained more impurities than the other investigated types and diameters and these would result into losses of strength properties, especially the softening of the intergranular layers when they are subjected to high temperature.

The 12mm diameter bars also showed low Phosphorous (P) content value of 0.004 to

0.008% compared to the 16mm and 20mm diameter bars with value ranging between 0.010-0.018% and 0.015-0.026% respectively. As the phosphorus content increased, there is tendency for increase in ductility and achievement of crack effects. It was also observed that the locally available 12mm diameter steel bars contained no traces of Boron (B), which would make the bars weak in strength and reduced its ductility. Sulphur (S) produced the most pronounced segregation of all constituent elements and sometimes added to steel for automatic machining up to 0.4%. The 16mm and 20mm diameter steel bars showed a sulphur content range between 0.023% and 0.046% while that of the 12mm diameter bar was below 0.005%, thus resulting into reduction of toughness in transverse direction and increase in the ductility and susceptibility to cracks of the 12mm diameter bars.

3.2 Mechanical Analysis of Reinforcing Steel Bars

Table 3.2 showed the strength characteristics of the high yield steel samples tested. The effective diameters of the locally produced high yield reinforcing steel bars were less than the code standard sizes. For example, the results showed 11.539mm, 15.329mm and 19.612mm respectively for standard diameter of 12mm, 16mm and 20mm. The diameters of the imported high yield steel were really according to those in the code standard. (9) For high yield steel, the British Standard, BS 4449, specified a yield stress of 460 N/mm^2 while the Nigerian Standard, NIS 117: 1992 specified 420 N.mm^2 (minimum). It was observed that all the steel samples fell below the standard recommended, especially the locally manufactured 12mm, 16mm, and 20mm diameter bars which had critical yield stress values of 63.76, 145.86 and 204 N/mm^2 respectively. The imported bars had higher values but still failed to meet the standard except the 20mm diameter bar with a yield stress value of 526.55 N/mm^2. This was the only bar that complied with the Codes of Practice and this makes it possible to recommend it for constructional work purposes. The average ultimate stress of the locally manufactured bar is about 289.02 N/mm^2, which implied that the mean tensile stress is very low, signifying brittleness while the imported bars had an average value of about 488.93 N/mm^2, which is a little more reasonable but still not sufficient enough.

The imported bars, the 12mm, 16mm and 20mm diameter bar had higher percentage elongation of 8.60% 12.87% and 7.77% respectively, all of which fell below the recommended value of 10%

according to the Nigerian standard. (9) For the locally manufactured bars, the 12mm, 16mm and 20mm diameter bars had percentage elongation values of 13.33, 17.67, and 18.90 percent respectively. These values are closes to the recommended values for mild steel of 20mm (min) and than that of the high yield bars.

The stress-strain curves of the locally manufactured bars, in Figure 3.1, showed that there was no defined yield point for the 12mm and 16mm diameter bars. Their yield points were almost at their point of failure, which signified hardness and brittleness. The ultimate failure is characterized by sudden breaking and snapping of the steel sample. At this stage, No plastic deformation was noticed, and ultimate failure occurred through the snapping of the bars. The 20mm diameter locally manufactured bar showed gradual increase in the strain is the increased stress, up to a limit of proportionality. With further loading, yield point was observed at a stress of about 250N/mm^2 when the steel began to yield. Further increase in stress made the steel to approach its ultimate value with the strain being more pronounced with little or no increase in stress. After yielding, there was sufficient plastic deformation before ultimate failure occurred.

The stress-strain curves for imported bars, in Figure 3.1, showed that the 12mm diameter high yield bar has no defined yield point and gave no sign when approaching its breaking point and also no further plastic deformation noticed. The mode of failure showed little or no necking and hardly any cup or cone surfaces. This indicated brittle behaviour. For the 16mm and 20mm diameter bars, as the strain increased there was corresponding increase in the stress values. There were enough plastic deformation before the final failure occurred. The comparison of all the steel reinforcement bars, both locally manufactured and imported, it showed that only the imported 16mm and 20mm diameter bar showed the required stress-strain characteristics diagram that could be recommended for structural concrete works. They would even resist more tensile stress compared with the locally manufactured steel bars tested.

3.3 Behaviour of Concrete Beams, Reinforced with the Steel Bars.

Table 3.3 and Figure 3.3 showed the load–central deflection values and curves of the beams reinforced with different types of the steel bars. It could be observed that the values of the ultimate collapse loads of the beams with the high yield imported steel bars were about $1^{1/2}$ times more than the beams with corresponding locally produce high yield bars.

However, the beams with 12mm diameter bars behaved just like those with 16mm diameter bars as the main reinforcement. For example, the beams with 12mm diameter local reinforcement failed at a load of 29.43kN while the corresponding beam with 16mm diameter locally produced reinforcement failed under 34.34kN load. For the beams with imported bars, the collapse loads were 54.96kN and 49.05kN respectively for 12mm and 16mm diameter bars. The beams reinforced with 20mm diameter bars produced the highest average load capacity especially the imported ones, which had an average value of about 75.5kN. It was also observed that the concrete beams reinforced with locally manufactured steel bars deflected more than the corresponding imported ones under the same applied load. The central deflection at the appearance of first crack in both 12mm and 16mm reinforced beams were almost equal. The beams reinforced with 12mm bars showed higher ductility as the deflection value at the ultimate load was more than three times the value at the appearance of the first crack. The failure patterns of the beams, shown in Figure 3.2, indicated that for the reinforced concrete beams with 12mm diameter local steel bars, the cracks occurred at the lower fibre around the mid-span and moved vertically up on the side. This was a flexural failure caused by the inadequacy of the main reinforcement. All other beams, reinforced with 12mm diameter (Imported), 16mm diameter (Local and Imported) and 20mm diameter (local and imported), failed with inclined cracks appearing from the lower fibre, near the support and moving toward the point of load application in the upper fibre. Minor vertical cracks were also observed near the midspan of the lower fibre and moving toward the top. Thus, indicating diagonal tension failure, with flexural failure in cases. The behaviour of the reinforcing bars in concrete beams was consistent with their chemical constituents and stress-strain characteristics.

4.0 CONCLUSION AND RECOMMENDATIONS

Based on the investigation on the structural characteristics of available reinforcing steel bars (locally produced and imported) in Nigeria, the following conclusion can be made:

1) The imported high yield steel bars contained higher value of ferrous and carbon contents than the corresponding

locally produced ones; thus resulting in higher yield and ultimate strength. The locally produced 12mm high yield bars contained only 0.166% carbon, which was less than the minimum permissible of 0.25%. There were higher impurities detected in the 16mm diameter bars, both local and imported, and this resulted into losses of strength properties.

2) The effective diameters of locally produced reinforcing bars were less than the codes standard diameters. They were about 5-10% less. The imported steel bars were adequate in terms of their diameters.

3) At the yield stresses of the steel samples tested fell below the BS 4449 recommended value of 460 N/mm^2 and Nigerian Standard of 420 N/mm^2 except the imported 20mm diameter steel bar with 526.55N/mm^2yield stress. While the locally produced were in the wide range of 63.76 to 204N/mm^2, the other imported steel values ranged between 317.86 and 207.31N/mm^2. The mean tensile stress of locally manufactured high yield steel bars were about 289N/mm^2, which is very low. The locally manufactured high yield steel bars behaved like the mild steel based on the elongation while the imported bars are close to the recommended values for high yield steel bars.

4) The stress-strain curves for the imported high yield steel bars showed no define yield point for 12mm diameter bars and their failure was signified by sudden snapping and pulling apart. However, for 16mm and 20mm diameter imported bars, there was enough plastic deformation before the final failure occurred could be recommended for structural concrete works. All the locally manufactured bars had no yield point and failed suddenly.

5) The behaviour of the reinforcing bars in the concrete beams was consistent with their chemical constituents and stress-strain characteristics. Beams reinforced with locally available imported steel bars had capacity of about one and half the value of the ultimate collapse loads of the corresponding locally manufactured steel bars. The failure pattern of the

beams with 12mm diameter bars was flexural while those with higher diameters was through diagonal tension failure, with cracks commencing from the support(s) towards the loading points.

It is recommended that only high yield imported bars with diameter of not less than 16mm should be used for structural concrete works while the assumed yield stress should be pegged around 280 - 300 N/mm^2 during the design. The locally manufactured high yield reinforcing bars should only be used for minor structural works.

It is further recommended that samples of the reinforcing steel bars should always be tested and their capacity confirmed prior to their use.

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Table 3.1: Percentage Chemical Constituent Elements in the High Yield Reinforcing Steel Bars

Constituent Elements	12mm diameter bars		16mm diameter bars		20mm diameter bars	
	Local	Imported	Local	Imported	Local	Imported
Fe	99.01	99.30	98.00	98.10	98.50	98.90
C	0.166	0.266	0.481	0.436	0.285	0.290
Si	0.335	0.348	0.332	0.346	0.305	0.325
Mn	0.368	0.380	1.000	1.090	0.840	0.370
P	0.008	0.004	0.010	0.018	0.026	0.015
S	0.001	0.005	0.033	0.046	0.036	0.023
Cr	0.001	0.000	0.000	0.001	0.001	0.004
Al	0.004	0.033	0.013	0.000	0.003	0.004
Co	0.010	0.009	0.006	0.005	0.003	0.000
Cu	0.073	0.034	0.004	0.029	0.009	0.010
Ti	0.006	0.004	0.008	0.006	0.038	0.073
B	-	-	0.001	0.004	0.004	0.006

Table 3.2 Mechanical Characteristics of Reinforcing Steel Bars

Diameter and Type of Steel Reinforcing bars	Effective Diameter (mm)	Weight of Steel bar (kg)	Yield Load (kN)	Ultimate Failure Load (kN)	Yield Stress (N/mm^2)	Ultimate Failure Stress (N/mm^2)	Elonga-tion (%)
12mm (Local)	11.539	0.492	6.67	36.00	63.76	248.52	13.33
12mm (Imported)	12.118	0.543	36.67	46.00	317.86	398.78	8.60
16mm (Local)	15.329	0.869	22.00	45.33	145.86	245.62	17.67
16mm (Imported)	15.562	0.896	40.00	83.33	207.31	438.22	12.87
2.0mm (Local)	19.612	1.423	62.00	112.67	204.99	372.92	18.90
20mm (Imported)	20.273	1.521	170.00	203.33	526.55	629.80	7.77

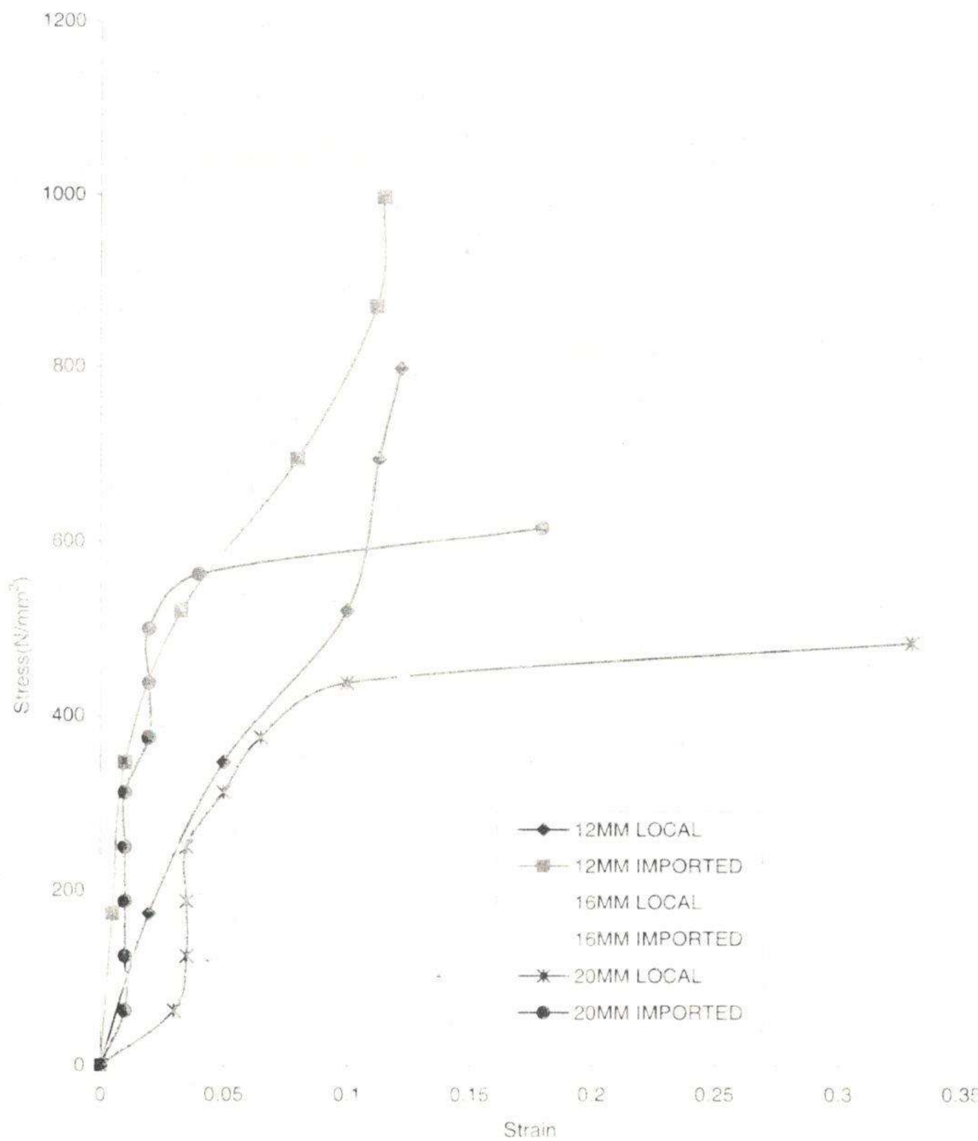

Figure 3.1: Stress-Strain curves of beams reinforced with different reinforcing bars

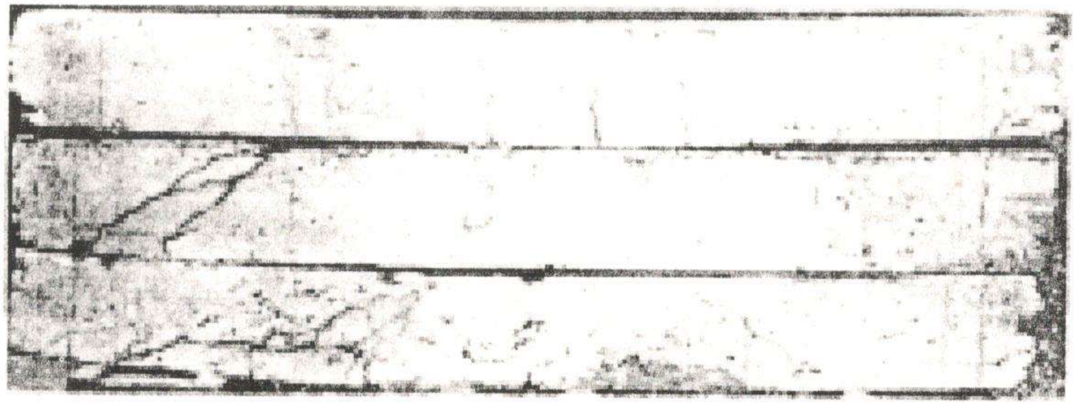

Figure 3.2(a): Beams reinforced with 12mm, 16mm & 20mm Ø bar (L)

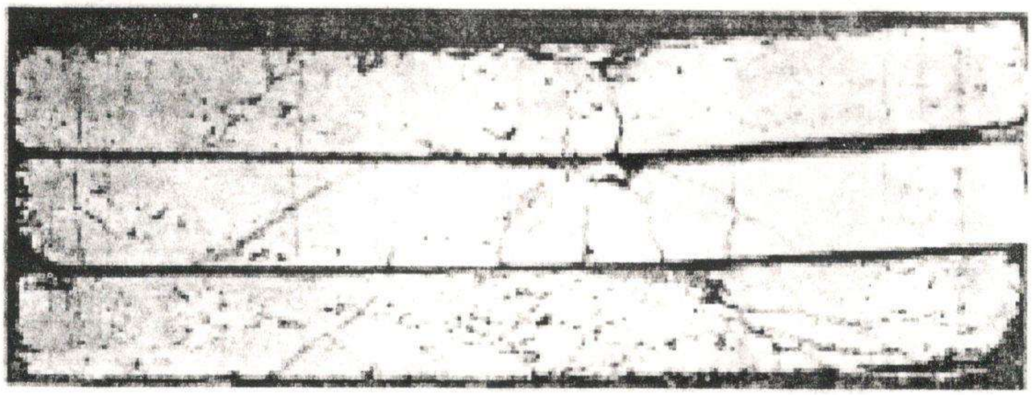

Figure 3.2(b): Beams reinforced with 12mm, 16mm & 20mm Ø bar (l)

Table 3.3. Load-Central Deflection Values Reinforced With Different Reinforcing Bars

Load	Deflection (10^{-2} mm)					
	12mm diameter bar		16mm diameter bar		20mm diameter bar	
(N)	Local	Imported	Local	Imported	Local	Imported
4905	118.0	113.5	110.5	91.0	102.0	80.5
9810	145.5	184.5	155.5	142.5	150.0	122.5
14715	220.5	257.0	165.5	220.0	202.0	142.0
19620	317.5	320.5	276.5	270.0	255.0	207.5
24525	410.0	406.5	368.0	329.0	314.5	247.0
29430	1375.5	467.5	477.0	418.0	378.5	291.0
34335		549	638.0	509.0	456.0	337.5
39240		634		649.0	549.0	388.0
44145		745		881.0	741.5	436.0
49050		897		1440.0		550.5
53955		1185				627.0
58860						712.0
63765						798.5
68670						960.0

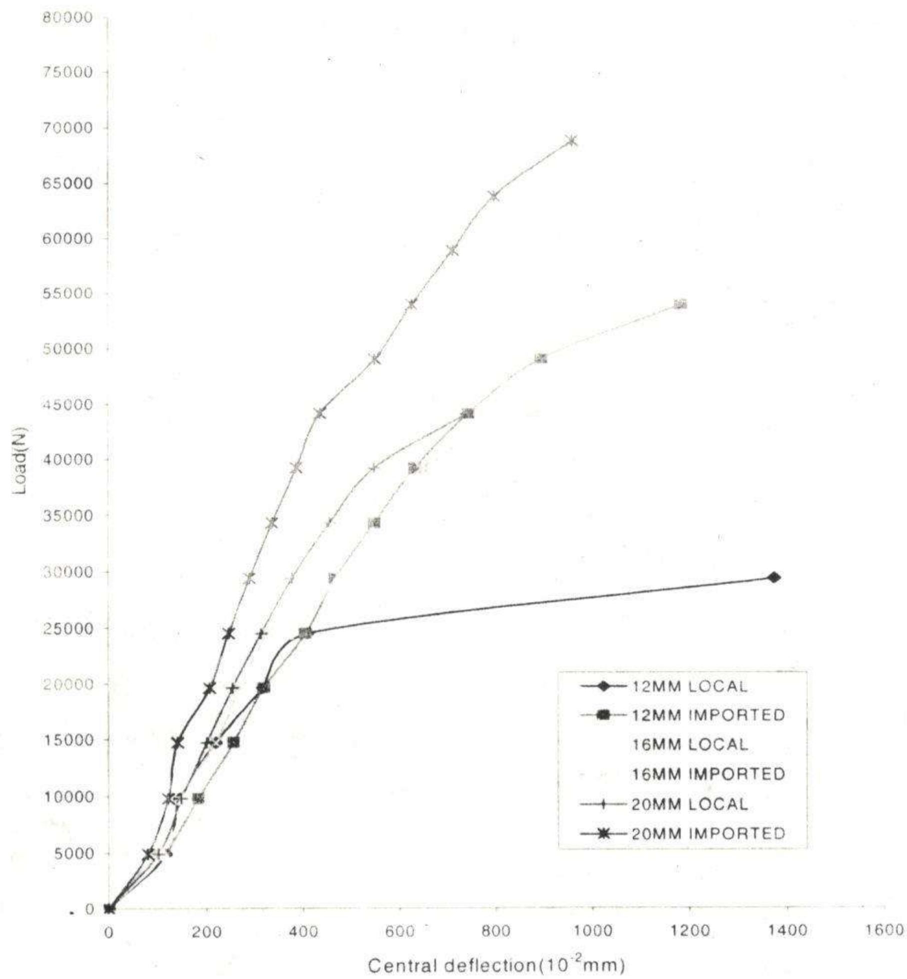

Figure 3.3: Load deflection curves of beams reinforced with different reinforcing bars