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GFRP Rebars: A Comparative Study

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ABSTRACT: Nowadays, there are lots of inland waterways that are in planning, design or construction stages in Dubai. The total length of these canals are exceeding few hundred kilometres and passing through the city. Each developer is proposing different types of retaining structure as an edge treatment of the waterway. The main idea of the first phase of this research was to select a particular area in Dubai and design three suitable types of side protection structures; diaphragm wall, post-tensioning diaphragm wall and blocks gravity quay wall. Following that a comparative assessment was carried out to find out the most suitable structural solution and associated reinforcement for the inland waterways in Dubai. Based on the overall study a recommendation was made for the most suitable type of lining structure for Dubai waterways. The results of this phase were published in a recent report at Dubai Mens College. The second phase which is the topic of this paper is to compare the mechanical properties of reinforcing bars available in the UAE with a deeper investigation of the new generation of Glass Fiber Reinforced Polymer (GFRP) rebars. The reason for selecting GFRP as a possible replacement for available reinforcement is its high durability.

The main aim of this paper is to assessing the possibility of using GFRP to replace the high strength carbon steel rebars via performing tensile tests on the new generation GFRP rebars of commonly used sizes in the construction industry ie., 8, 12, 16 mm diameter. The mechanical properties of the GFRP with the available carbon and stainless steel rebars in the Gulf region are compared. The compliance of the GFRP with both issues of British Standards BS 4449 (1997) and BS 4449 (2005) is checked as there is no other standard available yet for such bars in the Gulf. However, such bars are certified to the well known standard ACI 440.1R-06 (2006).

1 INTRODUCTION

Dubai has undergone a dramatic transformation of its waterfront in response to ambitious coastal developments involving massive land reclamations and inland waterways construction for the development of new residential and commercial districts.Historically, Dubai Creek (Fig 1b) was the only inland natural water body that divides the city of Dubai into two parts with sandy banks (Bur Dubai and Deira) with the total length of about fourteen kilometers. In the late 1960s, the decision was taken by Sheikh Rashid Bin Saeed, the former ruler of Dubai to develop the Creek in order to be suitable for dhows navigation. The development works included dredging the creek bed to an average depth of around 6.5 meter, and using the dredged material to develop adjacent land by building a new cargo imports handling area and reclaim Deira eroded coastline. A sheet pile wall was used to construct the lining of Dubai Creek. However, modern construction uses reinforced concrete walls.

During the past few years several huge man-made inland canals have been introduced as major elements of the mega development projects. Some of those inland waterways are already constructed and some other under construction. In addition to that, there are many artificial waterways are currently in the planning and design stages which are expected to be constructed during the few coming years. The total lengths of those water bodies are exceeding few hundreds of kilometers. All of the proposed canals will be connected to the Arabian Gulf Sea in order to allow the sea water to be circulated within the city, creating unique waterfronts and divide the city of Dubai to several islands or segments. Some of the constructed and the announced waterways projects in Dubai are for example, the Dubai Marina Canal which is a part of Dubai Marina Project in the Al Sofouh Area. Then comes the Business Bay Canal, which is a part of Business Bay Project and it is located in Ras Al Khor area. Arabian Canal is also one of the huge projects that will be mainly in Jebel Ali and will be considered as the largest man made waterway in the region with the total length of 75 kilometer that will run from the coast into the desert and a major harbor. Next comes the Meydan Canal which is a part of overall Meydan project which is located in Nad Al-Shiba. Finally comes the Union Canal which is a part of Mohammed Bin Rashid Gardens project which was announced some times in the beginning of the year. In addition to the above-mentioned waterways, there are many other canals which are in different stages of development. In all these later developments, the quay wall was constructed using a sheet pile wall, a block gravity wall, or more recently a diaphram wall. The main idea of the first phase of this research was to select a particular area in Dubai and design three suitable types of side protection structures; diaphragm wall, post-tensioning diaphragm wall and blocks gravity quay wall and compare them. Following that a comparative assessment was carried out to find out the most suitable structural solution and associated reinforcement for the inland waterways in Dubai. Based on the overall study a recommendation was made for the most suitable type of lining structure for Dubai waterways. The results of this phase were published in a recent report at Dubai Mens College (Al Raisi 2009). The second phase which is the topic of this paper is to compare the mechanical properties of reinforcing bars available in the UAE with a deeper investigation of the new generation of Glass Fiber Reinforced Polymer (GFRP) rebars. The reason for selecting GFRP as a possible replacement for available reinforcement is its high durability.

The main aim of this paper is to assess the possibility of using GFRP to replace the high strength carbon steel rebars via performing tensile tests on the new generation GFRP rebars of commonly used sizes in the construction industry ie., 8, 12, 16 mm. The mechanical properties of the GFRP with the available carbon and stainless steel rebars in the Gulf region are compared. Also the compliance of the GFRP with both issues of British Standards BS 4449 (1997) and (2005) is checked as there is no other standard available yet for such bars in the Gulf. However, such bars are certified to the well known standard ACI 440.1R-06 (2006).

Figure 1: (a) Dubai waterways (b) Dubai Creek quay sheet pile wall

2 PROPERTIES OF GFRP REBARS

GFRP, galvanized or stainless steel clad reinforcing bar may be employed in these situations at greater initial expense, but significantly lower expense over the service life of the project. They are available in many forms, from spirals for reinforcing columns, to the common rod, to meshes and many other forms. ComBAR® belongs (Schöck 2007) to the class of so called fiber composite materials. In fiber composites fibers are combined with other materials to achieve improved properties and synergy effects. The properties of the resulting material can be customized by choosing specific fibers, by adjusting the fiber orientation and by varying the additive and binder contents. One of the best known composites is glass fiber reinforced polymer (GFRP). It is being used in many fields, such as electronics and ship building, to produce light weight, high strength and extremely durable components.

The composite Schöck ComBAR now offers an entirely new range of applications in civil engineering. The reinforcing bar consists of a multitude of continuous fibers, oriented in the direction of the load, each with a diameter of approx. 20 µm. They are bonded in a resin matrix. The unique production process guarantees the complete impregnation of the glass fibers and an extremely high degree of curing. The fibers provide the longitudinal strength and stiffness of the material. The resin matrix holds the fibers in place, distributes the load and protects the fibers against damaging influences. The characteristic material properties of Schöck ComBAR® result from the uni-directional orientation of the fibers: high axial tensile strength, relatively low tensile and compressive strength perpendicular to the fibers. Loads acting perpendicular to the axis of the fibers pass through the resin first and then through the fibers. As a result, the material strength is limited by the weaker resin. The analogy to the natural construction material timber best describes the non-isotropic material properties.

3 TESTING PROGRAM

The procedure for preparing the 15 specimens was: (1) the specimens were cut to approximately 1100 mm long using a grinder machine; (2) the rebars were inserted into mild steel sleeve filled with epoxy and were left until the joint dried; (3) the specimen were inserted in between the machine grips; (4) the grip pressure was then applied which as 250, 350, and 400 bars for 8, 12, and 16, respectively. Finding the correct grip pressure is critical in performing such test, thus preliminary tests were performed to determine the most suitable values to avoid slip (see Fig 3); (5) after completion of the test, obtain the results from the testing machine and process them in MS Excel.

Figure 2 (a) tensile specimens ready for testing (b) 16 mm diameter specimen loaded in the machine

Figure 3 (a) slip mode for incorrect grip pressure (b) a specimen after applying the grip pressure

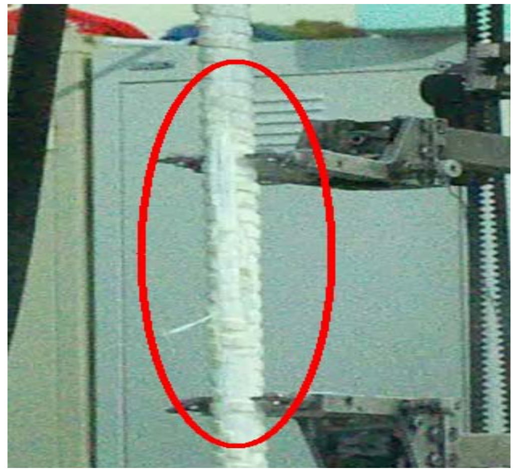
4 TENSILE TEST RESULTS

The tensile tests on GFRP rebars were performed to destruction at the Dubai Municipality Central Laboratory. The failure is fully documented in Figures 4-8 where it started by chipping of the ribs, then an initial split of the specimen and finally an interesting broom shape failure mode occurred (see Fig 4). It is seen in Figures 5-7 the similarity between the tests done at DMC and those done in Germany by Schock.

The average measured diagonal diameters (D_d) before the test commenced were 8.6, 13.1 and 17.5 for 8, 12 and 16 mm diameter bars, respectively. The average measured diameters (D_{av}) before the test commenced were 8.307, 12.66 and 16.71 for 8, 12 and 16 mm diameter bars, respectively. The average measured internal diameters (D_i) before the test commenced were 8.056, 12.153 and 15.96 for 8, 12 and 16 mm diameter bars, respectively. The average measured internal area (Ai) before the test commenced were 50.98, 116.01 and 200.07 mm^2 for 8, 12 and 16 mm diameter bars, respectively. The average measured tensile loads were 60.346, 156.76, and 277.85 kN for 8, 12 and 16 mm diameter bars, respectively. The average measured tensile stresses were 1183.65, 1351.24, and 1388.66 MPa for 8, 12 and 16 mm diameter bars, respectively. The average measured strains at maximum stress ($\%\varepsilon_{uk}$) were 2.24, 2.396, 2.816 for 8, 12 and 16 mm diameter bars, respectively. The average measured elongations (e %) were 2.44, 2.584, 3.752 for 8, 12 and 16 mm diameter bars, respectively. The average measured deviation from nominal mass were -1.37, -2.41, and 0.47 for 8, 12 and 16 mm diameter bars, respectively. These are lower than the +/- 4.5% in BS 4449.

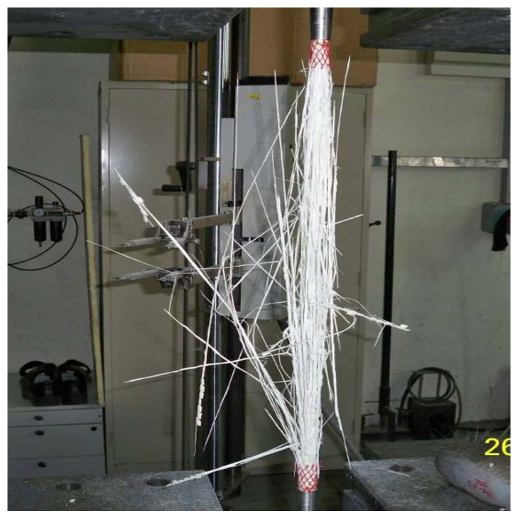
Figure 8 shows a comparison between the GFRP and the available carbon and stainless steel rebars in the Gulf. It is seen that the GFRP has a very large tensile strength, however the ductility is smaller than the others. In general, comparing the ComBAR stress strain diagram with the normal carbon steel (NCS), the following points can be noticed. The ultimate strength of the ComBAR is much higher than the normal carbon steel where it reaches with the ComBAR to almost 1400 N/mm2 and with the NCS and stainless Steel to maximum of around 700 and 900 MPa, respectively. The strain value is very low for the ComBAR where it is around 3 % and is much higher with NCS where reaches up to 16 % for 12 mm Dia and 23% for 16 mm Dia. This shows that the ComBAR is very brittle opposite to the NCS where it is ductile. It takes a long time for the NCS to fracture after the yield point where it is very short for the ComBAR, the reason why a higher safety factor should be considered for the GFRP while designing. The Young's modulus of the ComBAR which is almost 60 GPa is less than the one for the NCS which is 200 GPa as it is clear from the graph above. There is no necking region for the ComBAR where it is very long for the NCS.

(a) ComBAR specimen placed



(b) chipping of the ribs

(c) initial split of the specimen



(d) initiation of the brooming of the specimen

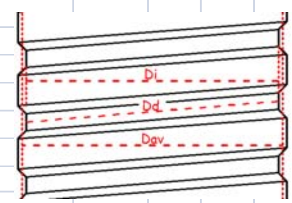
Figure 4 Progressive failure of ComBar GFRP rebars at DMC

5 CONCLUSIONS

Tensile tests on three commonly used sizes of GFRP rebars were performed to destruction. The failure was fully documented and it started by chipping of the ribs, then an initial split of the specimen and finally an interesting broom shape failure mode occurred. GFRP rebars in particular ComBar is a viable solution in the construction of diaphragm walls necessary for modern construction of quay walls required in the edge treatment of future waterways. Its combined superior tensile properties and durability qualify it as a viable alternative to the costly stainless steel and also to the required admixtures, inhibitors and special concretes in combination with carbon steel.

6 REFERENCES

ACI 440.1R-06, *Guide for the construction of structural concrete with FRP bars*, 2006.
Al Rraisi, A., *Edge treatment for Dubai inland waterways, durability assessment of diaphragm walls*, Bachelor Project, 2009.
BS 4449, British Standards, *tensile testing of carbon steel reinforcing bars*, 2005.
Schock, Technical information ComBar, 2007.

Sample Description:	ComBAR rebar										
Sample Source:	SCHÖCK - Germany										
Nominal Diameter, mm:	8										
					TEST RESULT						
							BS 4449 Specification				
Specimen No.	**1**	**2**	**3**	**4**	**5**	**Average**	**1997**		**2005**		
							A	**B**	**A**	**B**	**C**
Dimple	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**					
Dd	**8.6**	**8.6**	**8.6**	**8.6**	**8.6**	**8.6**					
Dav	**8.307**	**8.307**	**8.307**	**8.307**	**8.307**	**8.30696**					
Di	**8.057**	**8.057**	**8.057**	**8.057**	**8.057**	**8.05696**					
Mass, g	131.16	131.16	131.16	131.16	131.16	131.156					
Length, mm	1100	1100	1100	1100	1100	**1100**					
Load, Pu, KN	58.73	65.92	53.64	62.86	60.58	**60.346**					
Area, Ai, mm2	50.984	50.984	50.984	50.984	50.984	50.9838					
Yield Strength fy, N/mm^2	_	_	_	_	_	_	460 min.		400 to 600		
Ultimate Strength fu, Pu/Ai, N/mm^2	1151.9	1293	1052.1	1232.9	1188.2	**1183.63**					
Stress Ratio, fu/fy	_	_	_	_	_	_	1.05 min.	1.08 min.	? 1.05	? 1.08	? 1.15 <1.35
Final Gauge Length After Fracture, mm	_	_	_	_	_	_	80				
Total Elongation @ Maximum Force εuk, %	2.18	2.57	2.23	2.04	2.18	**2.24**	2.5 min.	5 min.	? 2.5	? 5.0	? 7.5
e, % (graph)	2.18	2.57	2.25	2.04	2.18	**2.244**	12 min.	14 min.			
Mass / Meter, g (theoretical)	129.3639132										
Deviation From Nominal Mass, %	-1.367	-1.367	-1.367	-1.367	-1.367	-1.36673	(+/-) 4.5				

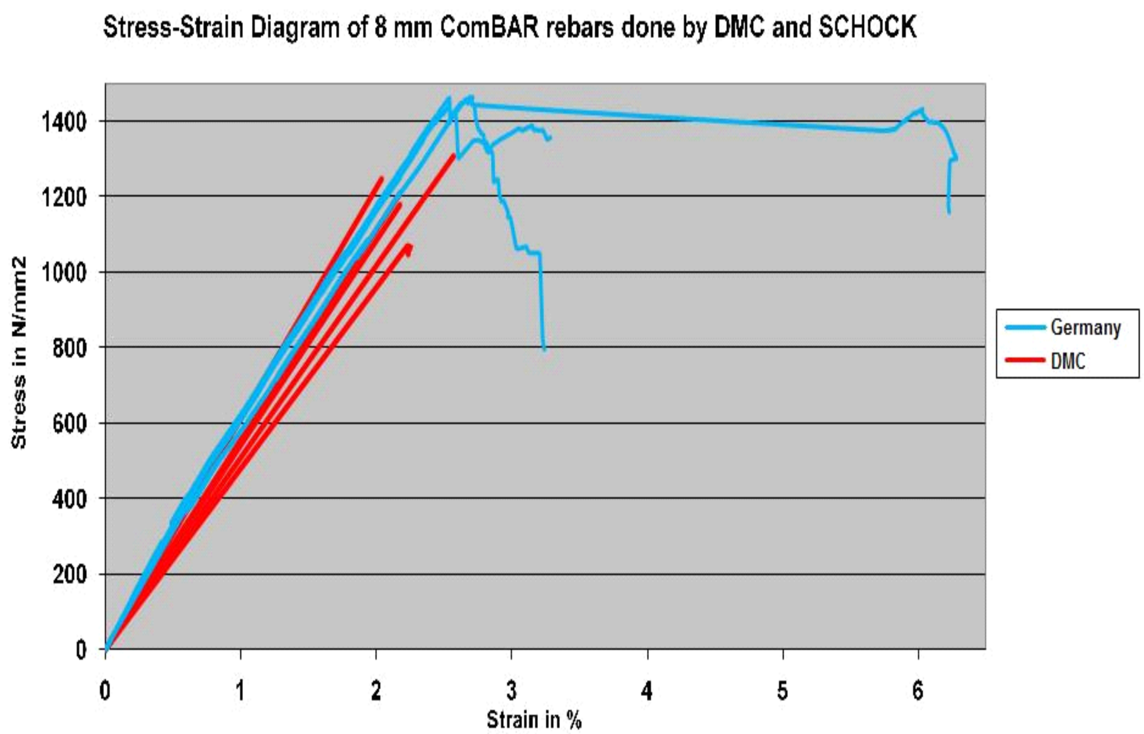
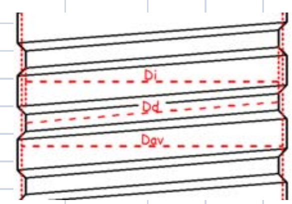


Figure 5: GFRP 8 mm diamter tensile test results.

Sample Description:	ComBAR rebar										
Sample Source:	SCHÖCK - Germany										
Nominal Diameter, mm:	12										
TEST RESULT											
							BS 4449 Specification				
Specimen No.	**1**	**2**	**3**	**4**	**5**	**Average**	**1997**		**2005**		
							A	**B**	**A**	**B**	**C**
Dimple	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**					
Dd	**13.1**	**13.1**	**13.1**	**13.1**	**13.1**	**13.1**					
Dav	**12.654**	**12.65**	**12.65**	**12.654**	**12.654**	**12.6536**					
Di	**12.154**	**12.15**	**12.15**	**12.154**	**12.154**	**12.1536**					
Mass, g	304.32	304.3	304.3	304.32	304.32	304.323					
Length, mm	1100	1100	1100	1100	1100	**1100**					
Load, Pu, KN	150.96	163.2	158.1	166.14	145.4	**156.76**					
Area, Ai, mm2	116.01	116	116	116.01	116.01	116.012					
Yield Strength fy, N/mm^2	_	_	_	_	_	_	460 min.		400 to 600		
Ultimate Strength fu, Pu/Ai, N/mm^2	1301.2	1407	1363	1432.1	1253.3	**1351.24**					
Stress Ratio, fu/fy	_	_	_	_	_	_	1.05 min.	1.08 min.	? 1.05	? 1.08	? 1.15 <1.35
Final Gauge Length After Fracture, mm	_	_	_	_	_	_	80				
Total Elongation @ Maximum Force εuk, %	2.48	2.6	2.1	2.6	2.2	**2.396**	2.5 min.	5 min.	? 2.5	? 5.0	? 7.5
e, % (graph)	1.92	2.6	2.25	3.95	2.2	**2.584**	12 min.	14 min.			
Mass / Meter, g (theoretical)	296.9786805										
Deviation From Nominal Mass, %	-2.413	-2.413	-2.413	-2.413	-2.413	-2.4135	(+/-) 4.5				

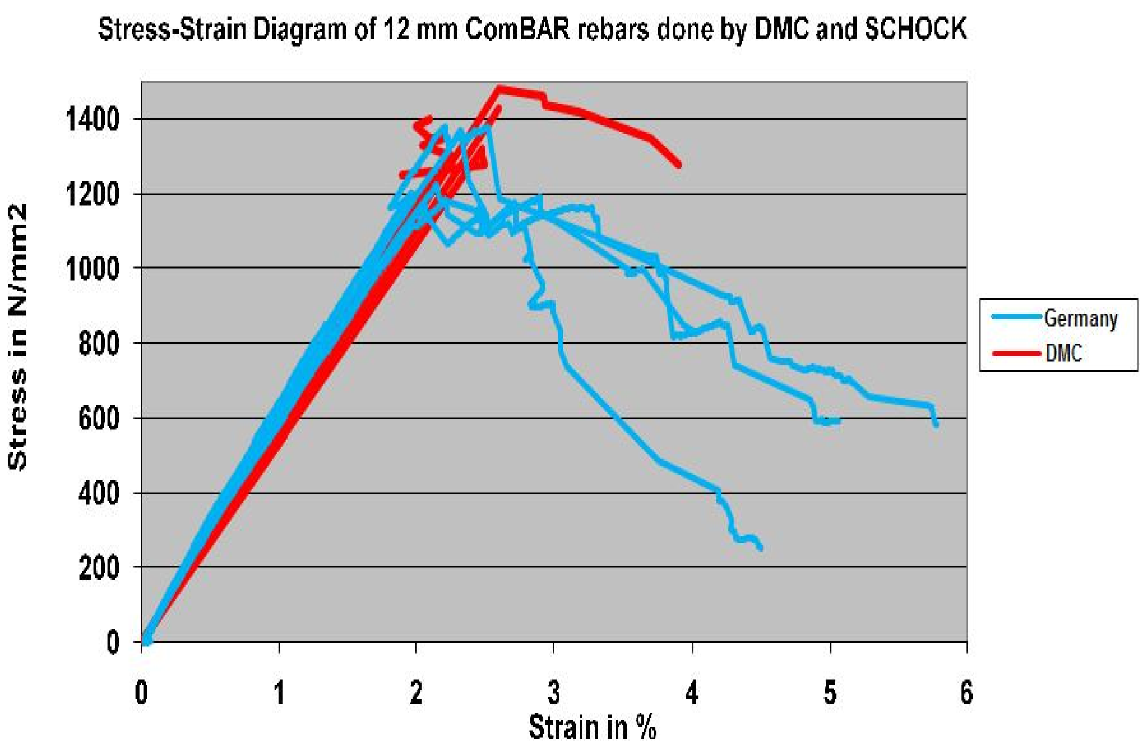
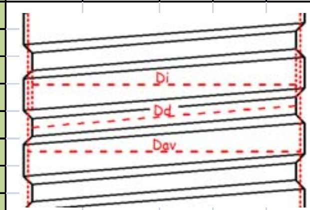


Figure 6: GFRP 12 mm diamter tensile test results.

Sample Description: ComBAR rebar
Sample Source: SCHÖCK - Germany
Nominal Diameter, mm: 16

TEST RESULT

							BS 4449 Specification				
Specimen No.	1	2	3	4	5	Average	1997		2005		
							A	B	A	B	C
Dimple	0.75	0.75	0.75	0.75	0.75	0.75					
Dd	17.3	17.3	17.3	17.3	17.3	17.3					
Dav	16.711	16.711	16.711	16.711	16.711	16.7105					
Di	15.961	15.961	15.961	15.961	15.961	15.9605					
Mass, g	530.74	530.74	530.74	530.74	530.74	530.744					
Length, mm	1100	1100	1100	1100	1100	1100					
Load, Pu, KN	276.1	269.38	283.35	269.59	290.73	277.83					
Area, Ai, mm2	200.07	200.07	200.07	200.07	200.07	200.071					
Yield Strength fy, N/mm^2	_	_	_	_	_	_	460 min.		400 to 600		
Ultimate Strength fu, Pu/Ai, N/mm^2	1380	1346.4	1416.2	1347.5	1453.1	1388.66					
Stress Ratio, fu/fy	_	_	_	_	_	_	1.05 min.	1.08 min.	? 1.05	? 1.08	? 1.15 <1.35
Final Gauge Length After Fracture, mm	_	_	_	_	_	_	80				
Total Elongation @ Maximum Force εuk, %	2.39	3.8	2.4	2.8	2.69	2.816	2.5 min.	5 min.	? 2.5	? 5.0	? 7.5
e, % (graph)	2.39	3.09	2.4	7.8	3.08	3.752	12 min.	14 min.			
Mass / Meter, g (theoretical)	533.2549188										
Deviation From Nominal Mass, %	0.4731	0.4731	0.4731	0.4731	0.4731	0.47311	(+/-) 4.5				

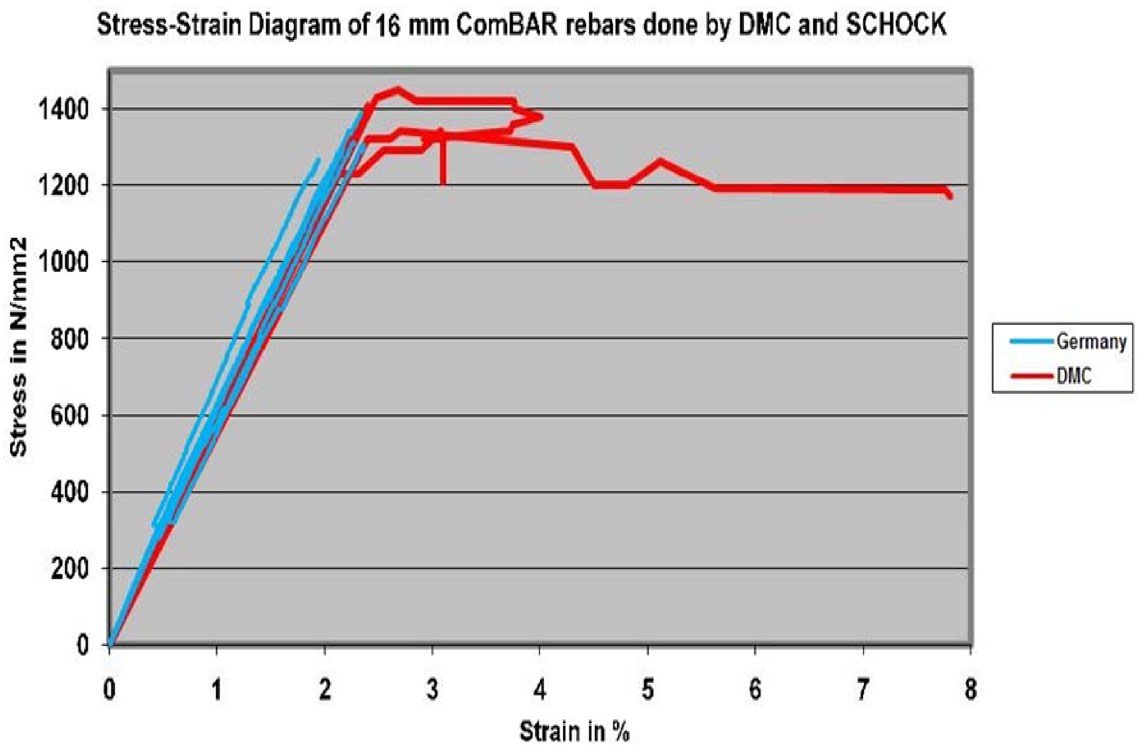
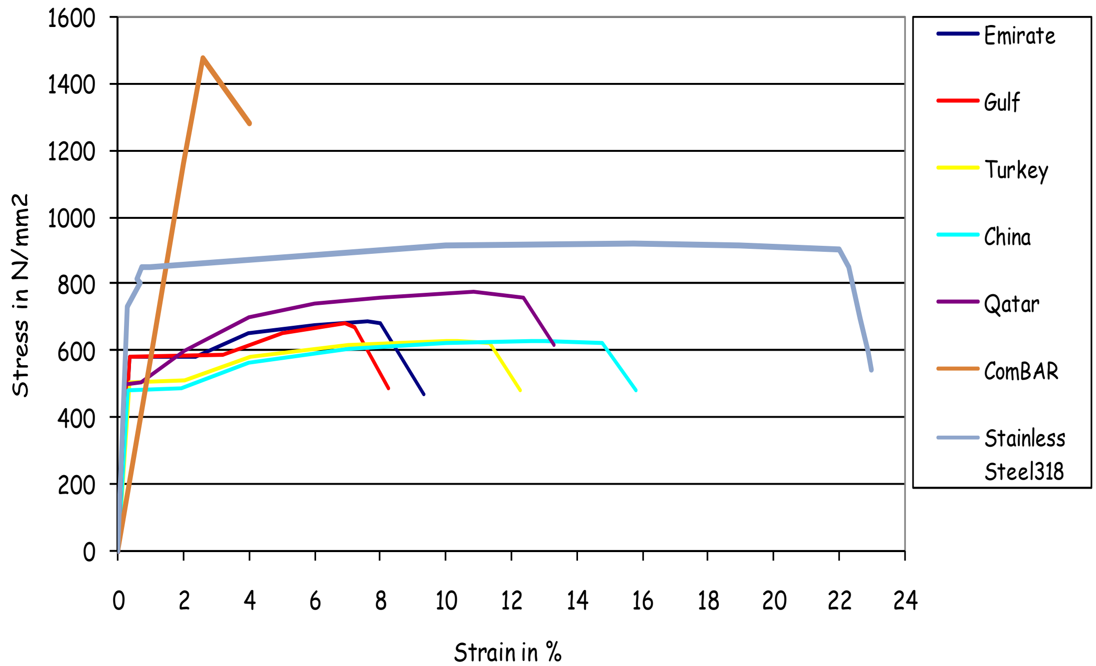
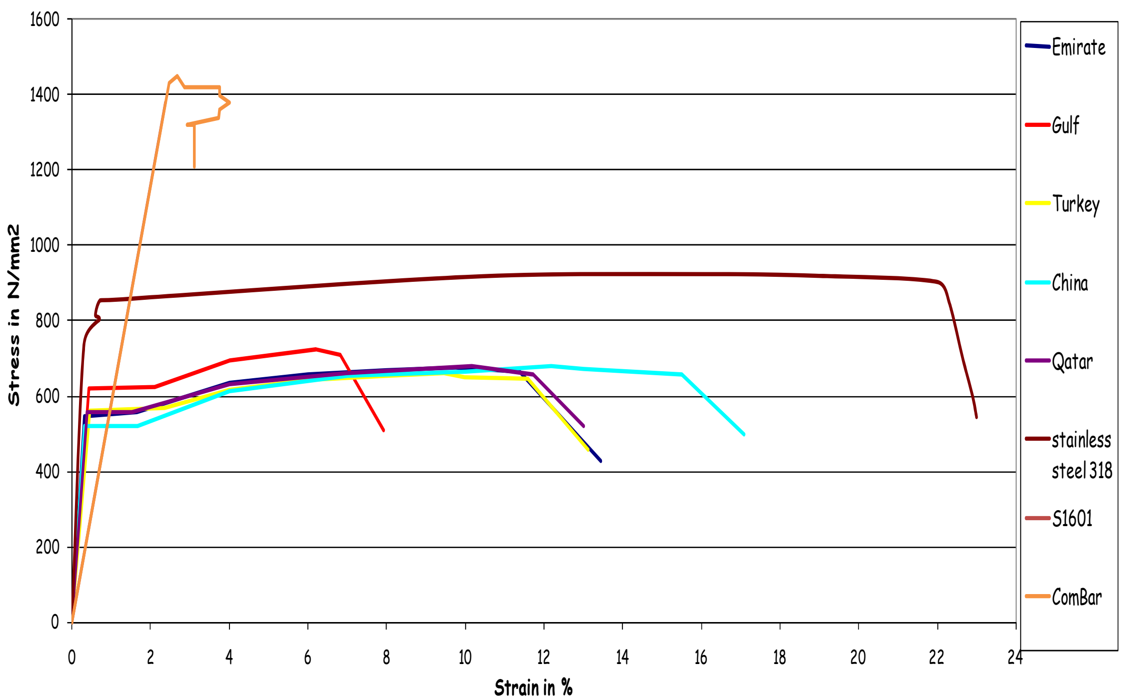


Figure 7: GFRP 16 mm diamter tensile test results.



(a) 12 mm bars



(b) 16 mm bars

Figure 8 Comparing GFRP and other carbon and stainless steels for 12 and 16 mm bars