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Strength and Durability of Recycled Concrete made from Recycled Aggregate and Wastewater

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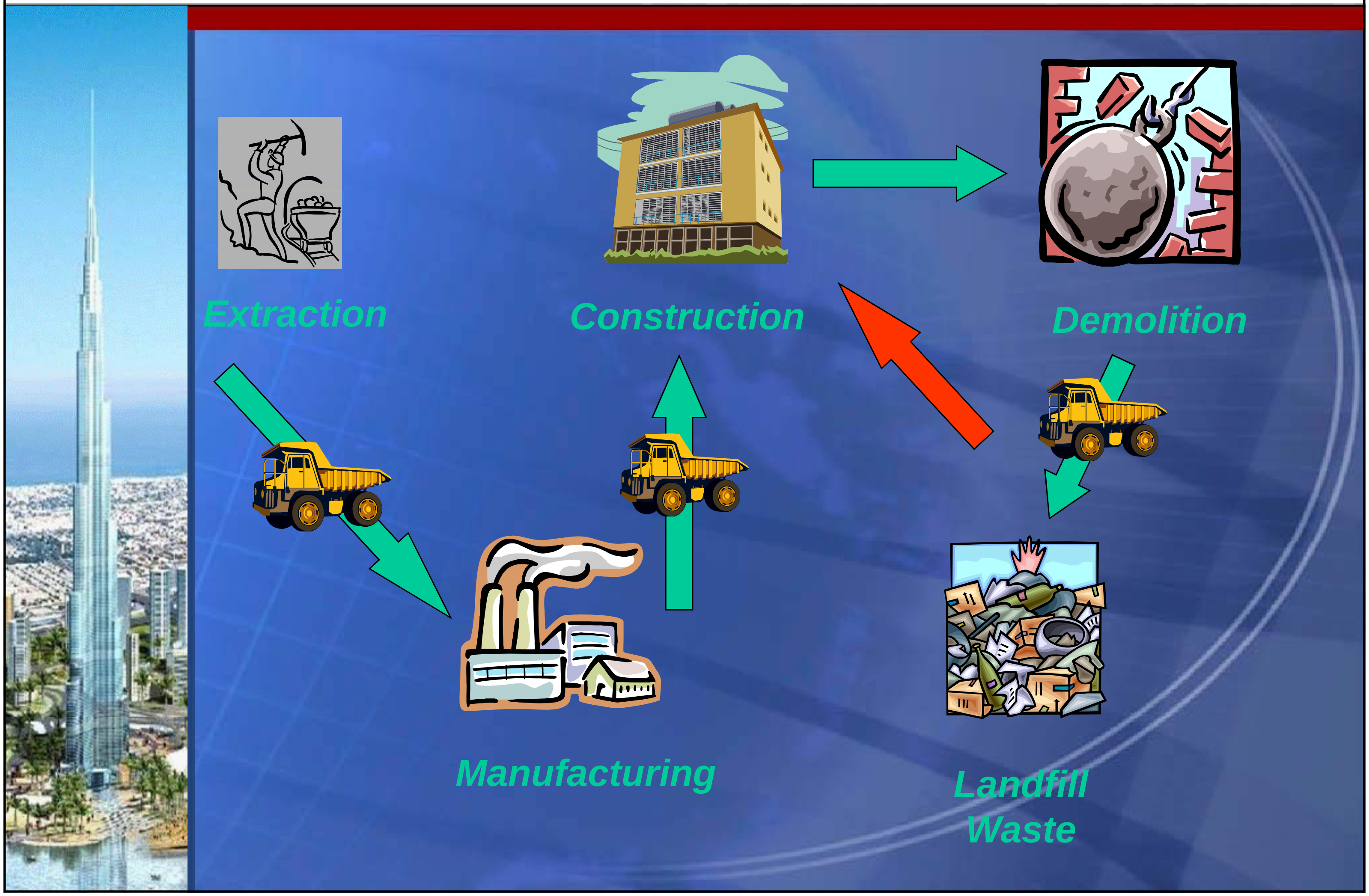
Session Outline

- C&D Waste Statistics
- The making of RC from DW
- Strength Results
- Durability Results
- Conclusions
- Future Research

The Current Material Process in the GCC

The one way stream Bob Scott ,ATKINS, 2010)



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Statistics for C&D Waste

Around 75% of the GCC Waste is from construction

The caption shows a Typical Construction Landfill Site in the GCC

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Statistics for C&D Waste

Waste	EU-27 High	EU-27 Low	USA	GCC
Total Municipal and C&D Waste (million ton/year)	2,900	1,228	380	120
C&D Waste (million ton/year)	727	307	130	90
% C&D /Total	25%	25%	35%	75%
Population (Millions in 2010)	501		310	40

In the USA alone 2.0 billion tons of fresh aggregate are produced every year and it will increase to 2.5 billion tons by 2020 (Fisher and Werge 2009).

Simply it is unsustainable from both point of views: the availability of virgin aggregate; and the wasted unused aggregate from demolition!!

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C&D Waste

C&D Waste:

- Concrete
- Asphalt
- Bricks
- Tiles
- Ceramic
- Gypsum
- Ozone Depleting Substances
- Dangerous substances such as Asbestos

EU-28 Target is to Recycle 70% of C&D Waste by 2020

Japan using 3R philosophy (reduce, Reuse, Recycle), is targeting 0% Waste Society by 2020

Country	Netherlands	Flanders	Denmark	Estonia	Finland	Czech Republic	Ireland	Spain	Germany
Year	2001	2000	2003	2006	2006	2006	1996	2005	2007
Concrete	40%	41%	25%	8%	33%	33%	39%	12%	70%
Masonry	25%	43%	6%			35%		54%	
Other mineral waste	2%	-	22%	53%	-	-	51%	9%	-
Total mineral waste	**67%**	**84%**	**53%**	**61%**	**33%**	**68%**	**90%**	**75%**	**70%**
Asphalt	26%	12%	19%	4%	-	-	2%	5%	27%

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What we already know!!
Comparison between RA and NA

When demolished concrete is crushed, a certain amount of mortar and cement paste from the original concrete remains attached to stone particles in recycled aggregate. This attached mortar and the increased water to rectify the slump are the main reasons for the lower quality of Recycled Aggregate (RA) compared to Natural Aggregate (NA). The RA compared to the NA has the following properties:

- increased water absorption
- decreased bulk density
- decreased specific gravity
- increased abrasion loss
- increased crushability
- increased quantity of dust particles
- possible content of chemically harmful substances
- Wide variation in mechanical properties depending on the amount of paste

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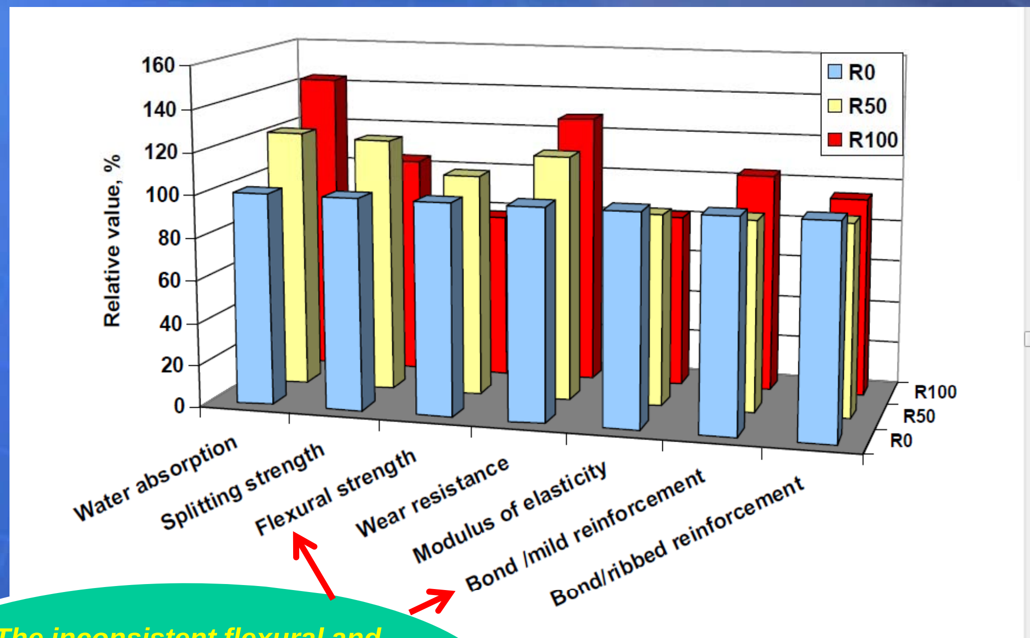
What we already know
Comparison between RC and NC



The inconsistent flexural and bond strength variations caused by cement paste!

The mechanical properties of hardened RC made from RA only is well documented, however RC made from RW or RW+RA is not yet known

(Data shown from Mirjana Maelesv etal., J. Sustainability, volume 2, 1204-1225, 2010)

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Test Program

- **The recycled aggregate was obtained from a demolition construction waste at Emirates Recycling Pty Ltd in Dubai. "Emirates Recycling" is an $18 million joint venture between Al Rostamani Group and the Italian General Work infrastructure development company. The average measured density was 2.51 t/m^3 and water absorption of the recycled aggregate was 5.2%. The received aggregates were sieved and the 10 and 20 mm sizes were separated and used in the mix.**

- **The Recycled Waste Water was obtained from the MBR process from a newly constructed wastewater treatment plant attached to a construction labor camp in Alquz suburb in Dubai.**

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Test Program and Matrix

% Recycle	RW Beams	RW+RA Beams	Type
0%	RW-P0%	RW/RA-P0%	Plain
	RW-B0%	RW/RA-B0%	Bottom Steel
	RW-T0%	RW/RA-T0%	Top Steel
	RW-TB0%	RW/RA-TB0%	Top+Bottom Steel
25%	RW-P25%	RW/RA-P25%	Plain
	RW-B25%	RW/RA-B25%	Bottom Steel
	RW-T25%	RW/RA-T25%	Top Steel
	RW-TB25%	RW/RA-TB25%	Top+Bottom Steel
50%	RW-P50%	RW/RA-P50%	Plain
	RW-B50%	RW/RA-B50%	Bottom Steel
	RW-T50%	RW/RA-T50%	Top Steel
	RW-TB50%	RW/RA-TB50%	Top+Bottom Steel
75%	RW-P75%	RW/RA-P75%	Plain
	RW-B75%	RW/RA-B75%	Bottom Steel
	RW-T75%	RW/RA-T75%	Top Steel
	RW-TB75%	RW/RA-TB75%	Top+Bottom Steel
100%	RW-P100%	RW/RA-P100%	Plain
	RW-B100%	RW/RA-B100%	Bottom Steel
	RW-T100%	RW/RA-T100%	Top Steel
	RW-TB100%	RW/RA-TB100%	Top+Bottom Steel

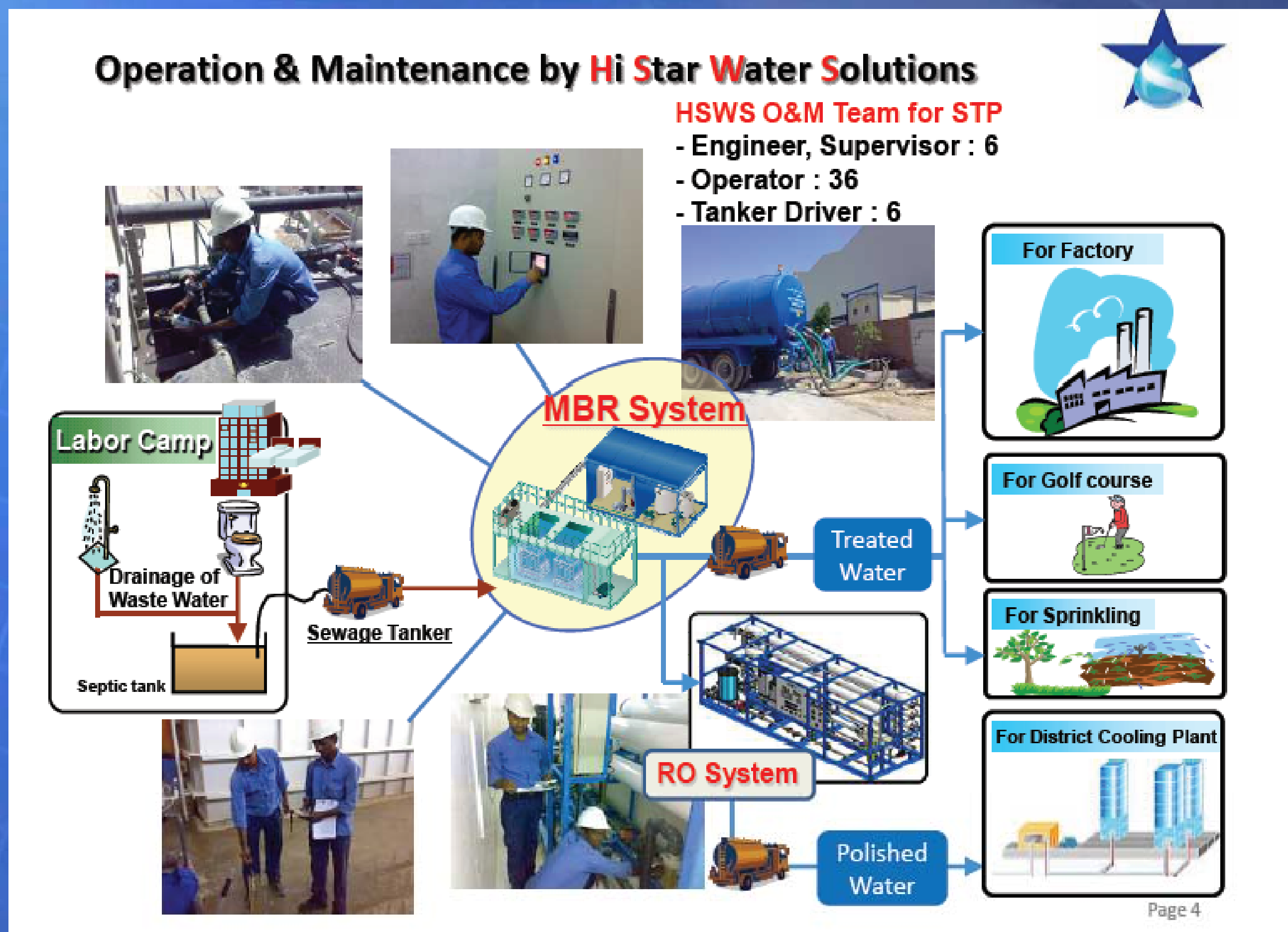
The test program involves the preparation of moderate strength concrete C40 out of recycled water and recycled aggregate. A total of 27 standard cubes 150x150x150 mm and 27 standard cylinders 150 mm diameter and 300 mm long were prepared to BS 1881-116 and 40 beams 600x150x150 mm to BS 1881-118. The control mix had 370 kg OPC, 159 kg of DEWA water, 559 kg of 20mm crushed RAK Rock, 365 kg of 10mm crushed RAK Rock, 699 kg of 5mm crushed RAK Rock and 238 kg dune sand. For the aggregate, only the 10 mm and 20 mm were replaced (The 0-5 mm size was not recycled) by recycled material after it was sieved.

Recycled Aggregate Plant in Dubai

Input Material

Material Cleaned and Crushed

Recycled Wastewater using Membrane Bioreactor (MBR) Process



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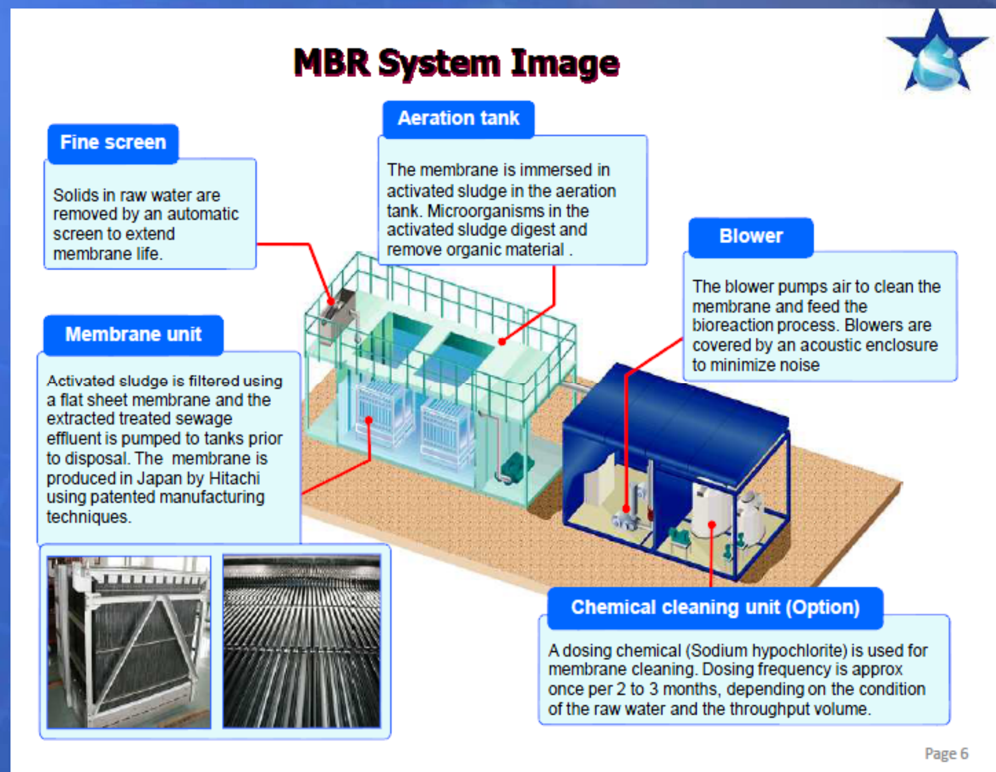
Recycled Water using Membrane Bioreactor (MBR) Process



http://www.youtube.com/watch?v=fxHmLK9u7H4&NR=1

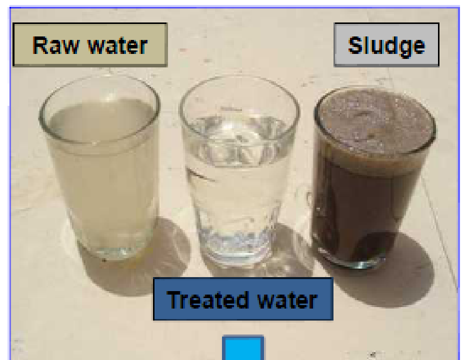
http://www.youtube.com/watch?v=xpr2IV-eSOg&feature=related

Recycled Water using MBR Process

BENEFIT: High-quality treated water: MBR

Item		Raw water	Treated water: Comparison	
			Membrane system	Conventional (OD system)
BOD	(mg/L)	193	1.0	20
COD	(mg/L)	124	7.5	25
T-N	(mg/L)	38	5.7	5.7
T-P	(mg/L)	7.8	0.3	0.5
SS	(mg/L)	250	<0.4	20
Coliform	(CFU/mL)	3.7×10^5	No detection	<3000
Escherichia Coli phage (Virus)	(PFU/100mL)	3.6×10^5	1	2.7×10^2

For effective filtration, Membrane's pore size is 0.1μm, the pathogens, coliforms and helminth egg can be removed. Treated water can be recycled for landscape water irrigation, etc. High performance for separation



Above mentioned Figures are Sample Figures for your reference

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Recycled Water using MBR Process

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RC Project Photos

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Beam Specimen Schmeatic

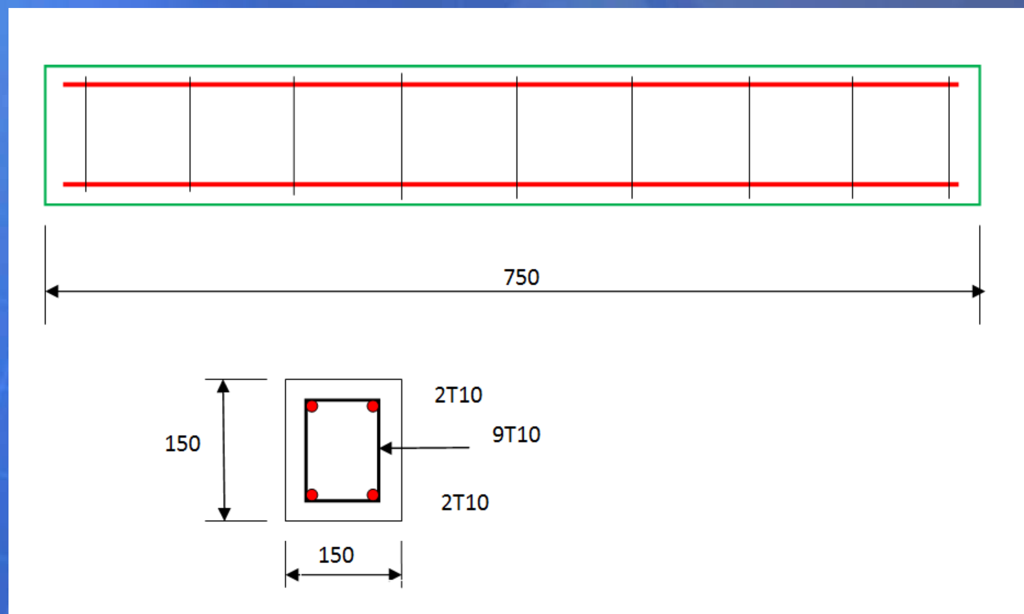

Figure 2 Beam Geometry and Reinforcement

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Test Results: Cube Strength

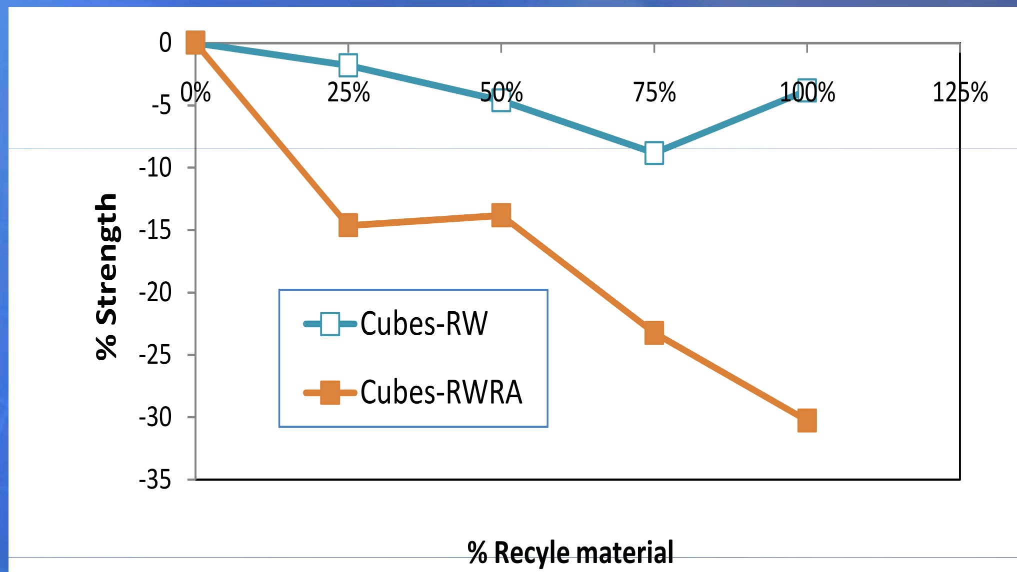

Figure 3 Effect of %recycled material on axial cube strength

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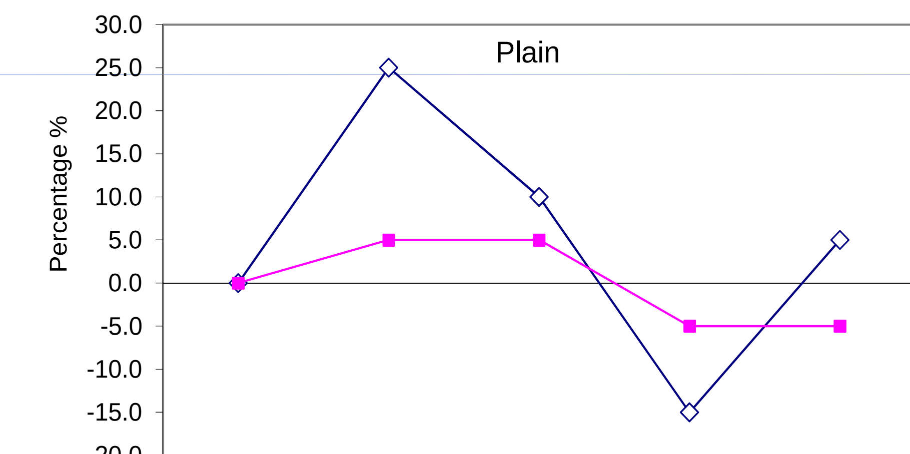
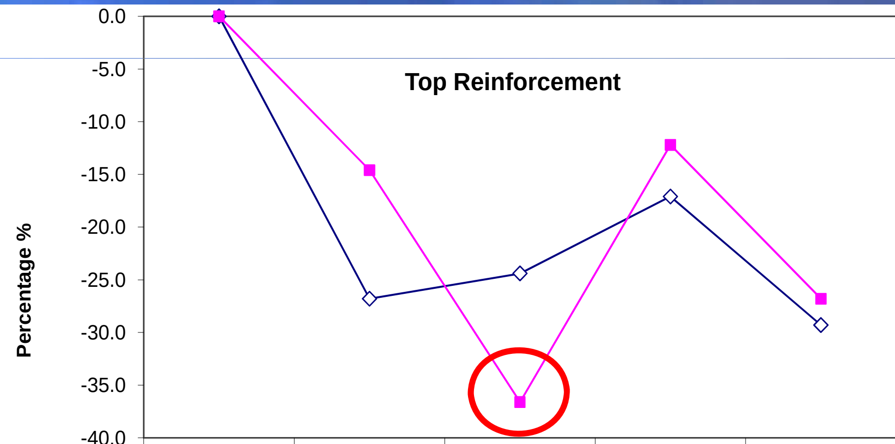
Test Results: Bending Strength of Beams



	0%	25%	50%	75%	100%
RW	0.0	25.0	10.0	-15.0	5.0
RW-RA	0.0	5.0	5.0	-5.0	-5.0

Figure 5 Effect of % recycled material on plain beam bending strength

Test Results: Bending Strength of Beams



	0%	25%	50%	75%	100%
RW	0.0	-26.8	-24.4	-17.1	-29.3
RW-RA	0.0	-14.6	-36.6	-12.2	-26.8

Figure 6 Effect of % recycled material on beam bending strength with top reinforcement

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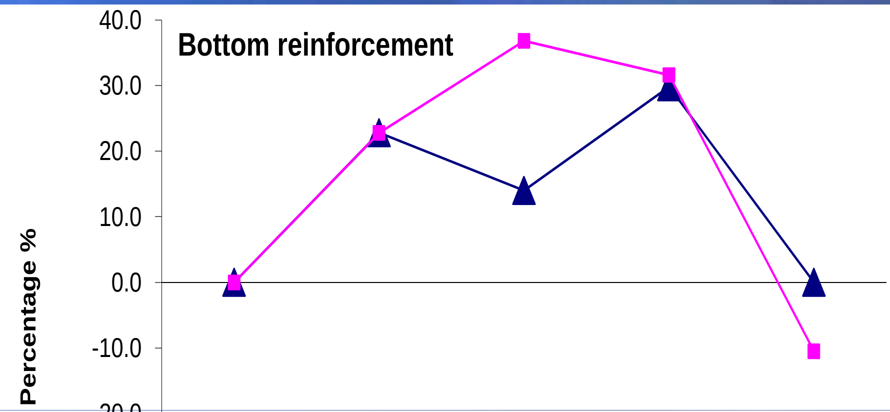
Test Results: Bending Strength of Beams



	0%	25%	50%	75%	100%
RW	0.0	22.8	14.0	29.8	0.0
RW-RA	0.0	22.8	36.8	31.6	-10.5

Figure 7 Effect of % recycled material on beam strength with bottom reinforcement

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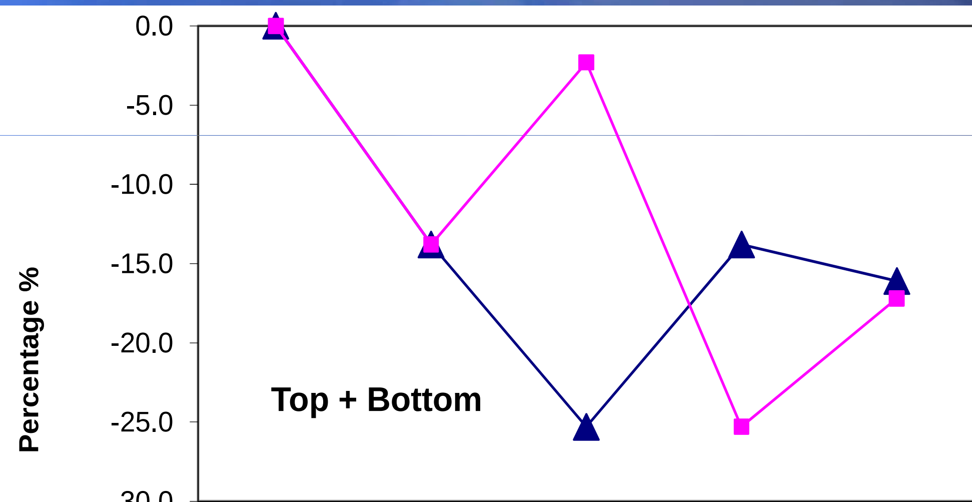
Test Results: Bending Strength of Beams



	0%	25%	50%	75%	100%
RW	0.0	-13.8	-25.3	-13.8	-16.1
RW-RA	0.0	-13.8	-2.3	-25.3	-17.2

Figure 8 Effect of % recycled material on beam strength with bottom reinforcement

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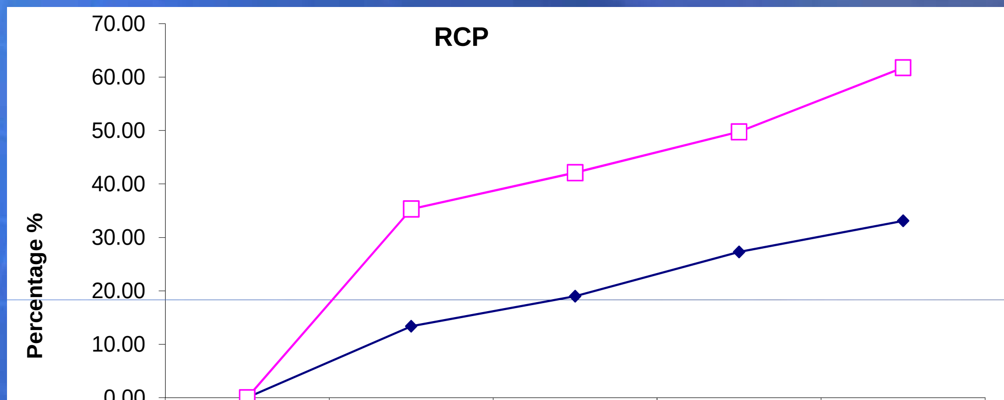
Test Results: Durability

Rapid Chloride Penetration Test to ASTM C1202

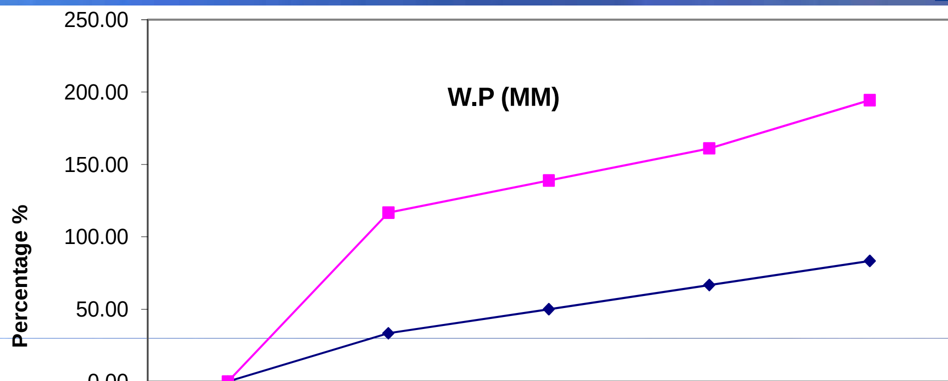


	0%	25%	50%	75%	100%
RW	0.00	13.37	19.00	27.27	33.10
RW-RA	0.00	35.32	42.11	49.76	61.76

Figure 9 Effect of % recycled material on durability by using RCP test

Test Results: Durability

Water Permeability Test to BS EN 12390-8



	0%	25%	50%	75%	100%
RW	0.00	33.33	50.00	66.67	83.33
RW-RA	0.00	116.67	138.89	161.11	194.44

Figure 10 Effect of % recycled material on durability by using WP test

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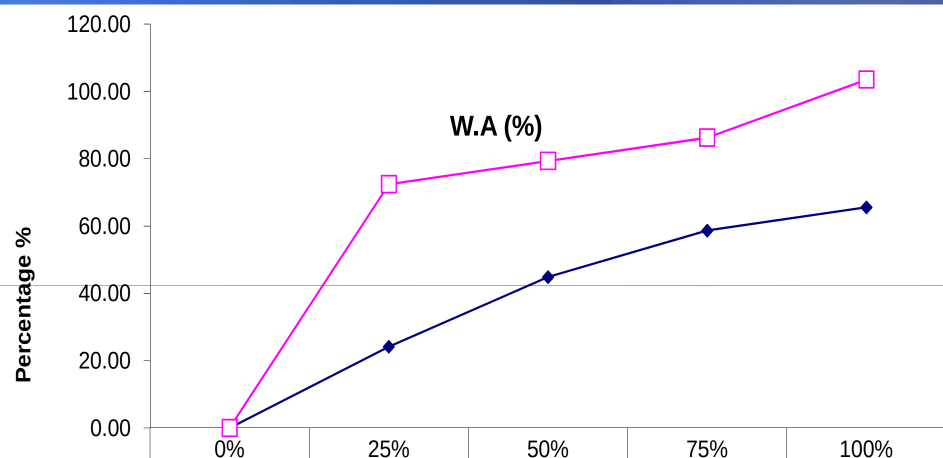
Test Results: Durability

Water Absorption Test to BS 1881-122



	0%	25%	50%	75%	100%
RW	0.00	24.14	44.83	58.62	65.53
RW-RA	0.00	72.41	79.31	86.21	103.45

Figure 11 Effect of % recycled material on durability by using WA test

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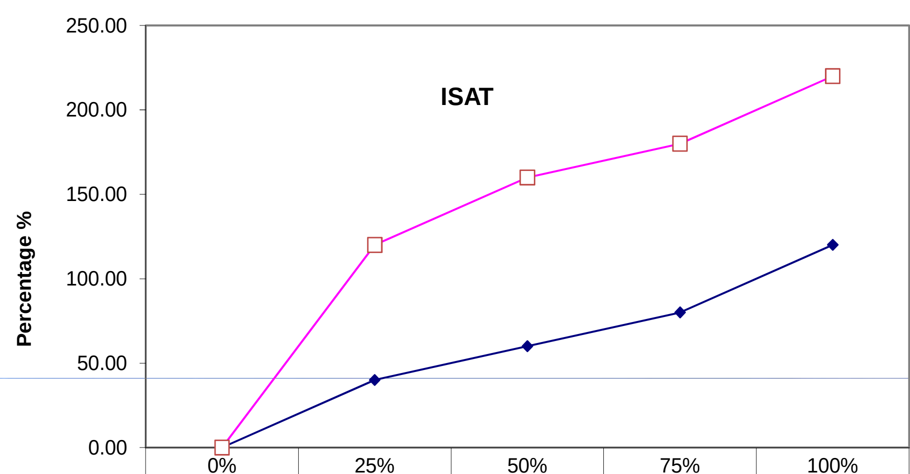
Test Results: Durability

Initial Surface Absorption Test to BS 1881-208



	0%	25%	50%	75%	100%
RW	0.00	40.00	60.00	80.00	120.00
RW-RA	0.00	120.00	160.00	180.00	220.00

Figure 12 Effect of % recycled material on durability by using ISAT test

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GGBS Replacement in Recycled concrete

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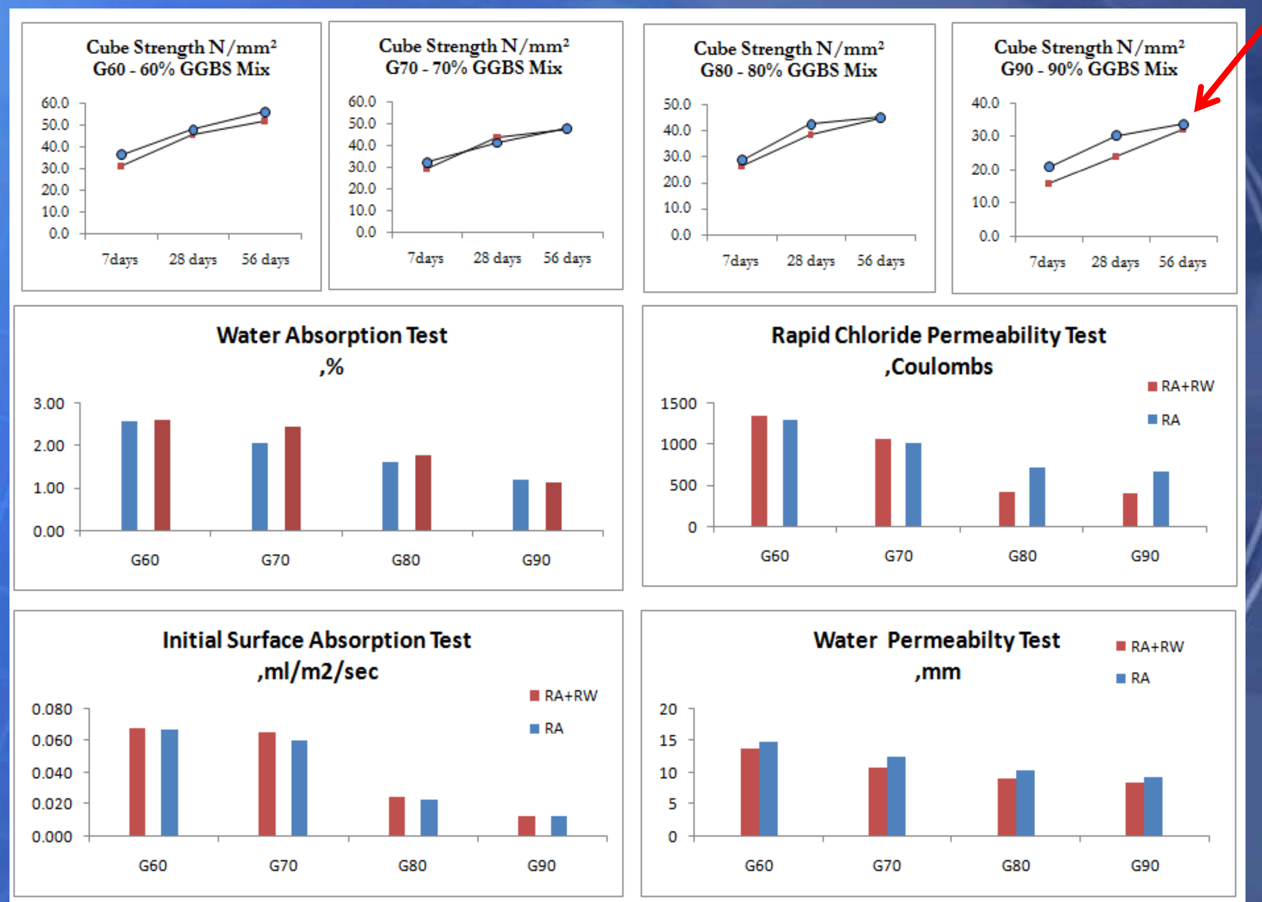

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CO2 Emissions

Control Mix

	Material	Source	Co2 kg/Ton	Cost/m3	Mat(kg)/m3	Cost/m3	Co2 kg /m3
Binder	OPC	UAE	959	240	370	88.8	354.83
	GGBS	UAE	155	280	0		
	Fly Ash	India	93	300	0		
Total Binder					370		
	Water	UAE	1	25	159	3.975	0.159
	W/C				0.43		
Aggreegates	20 mm Aggregate	RAK	7	48.5	559	27.1115	3.913
	10 mm Aggregate	RAK	7	48.5	365	17.7025	2.555
	5 mm Aggregate	RAK	7	51	699	35.649	4.893
	Dune Sand	AL Ain	5	25	238	5.95	1.19
Total Aggregates					1861		0
Admixture kg/m3 SP 495			508	5	5.5	27.5	2.794
Total Co2 kg/m3							**370**
Total Cost/m3						**207**	

G80 - 80% GGBS Replacement

	Material	Source	Co2 kg/Ton	Cost/m3	Mat(kg)/m3	Cost/m3	Co2 kg /m3
Binder	OPC	UAE	959	240	56	13.44	53.704
	GGBS	UAE	155	280	314	87.92	48.67
	Fly Ash	India	93	300	0		0
Total Binder					370		
	Water	UAE	1	25	159	3.975	0.159
	W/C				0.43		
Aggreegates	20 mm Aggregate	RAK	7	48.5	559	27.1115	3.913
	10 mm Aggregate	RAK	7	48.5	365	17.7025	2.555
	5 mm Aggregate	RAK	7	51	699	35.649	4.893
	Dune Sand	AL Ain	5	25	238	5.95	1.19
Total Aggregates					1861		0
Admixture kg/m3 SP 495			508	5	5.5	27.5	2.794
Total Co2 kg/m3							**118**
Total Cost/m3						**219**	

Case Study

Burj Khalifa has 330,000 m3 of concrete. Reduction in Carbon foot print if G80 Recycled Concrete was used =330,000x(370-118)/1000=85,800 ton.

This represents:

85,800/6/100=143 passenger cars emissions per 100 year the design life of the building.

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LEED 2009 Certification- Case Study

MR Credit 4: Recycled Content

- **Intent**

To increase demand for building products that incorporate recycled content materials, thereby reducing impacts resulting from extraction and processing of virgin materials.

- **Requirements**

Use materials with recycled content1 such that the sum of post-consumer recycled content (such as C&D waste) plus 1/2 of the pre-consumer content (such as scrap metal) constitutes at least 10% or 20%, based on cost, of the total value of the materials in the project. The minimum percentage materials recycled for each point threshold is as follows:

Recycled Content	Points	Comments
10%	1	Based on cost
20%	2	Based on cost

- **Case Study**

Assuming that the concrete represents 40% of the total building cost:

- For 25% Recycled Agg Concrete → 0.25x0.40 = 10% Recycled content → 1 Point

- For 50% Recycled Agg Concrete→ 0.50x0.40 = 20% Recycled content → 2 Points

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LEED 2009 Certification- Case Study

WE Credit 2: Innovative Wastewater Technologies

- **Intent**

To reduce wastewater generation and potable water demand while increasing the local aquifer recharge.

- **Requirements**

Option 1: Reduce potable water use for building sewage conveyance by 50% through the use of water-conserving fixtures (eg. Water closets, urinals) or non-potable water (eg. Captured rain water, recycled grey water, onsite or municipality treated water).

Option 2: Treat 50% of wastewater onsite to tertiary standards

Recycled Content	Points	Comments
Reduce potable water by 50%	2	Option 1
Treat wastewater on site 50%	2	Option 2

- **Case Study**

- Treat 50% waste water using MBR System on Site → 2 Points

- Treat 25% waste water using MBR System on Site → 1 Point

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Conclusions

- The effect of recycled aggregate and water on axial and bending strength was found moderate and less than 40% but had a significant effect on durability which was of the order of 200%.
- The effect of increasing the percent of the recycled water and recycled aggregate RW+RA on axial strength of cubes and cylinders is more pronounced compared to recycled water RW only.
- The beams with bottom reinforcement had the most severe effect on bending strength which was in the order of 24% for RW and 36% for RWRA.
- The deterioration in the durability for RWRA was almost double the one for RW only.
- To enhance the durability of recycled concrete and to reduce Co2 emissions , GGBS and or Fly Ash should be used for any future building construction in the Gulf.

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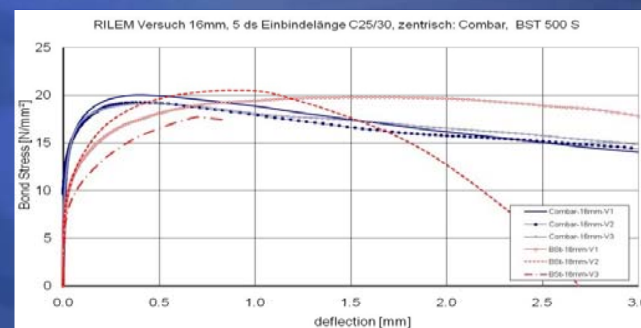
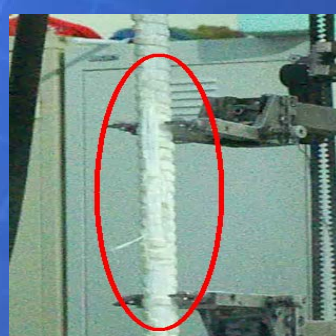
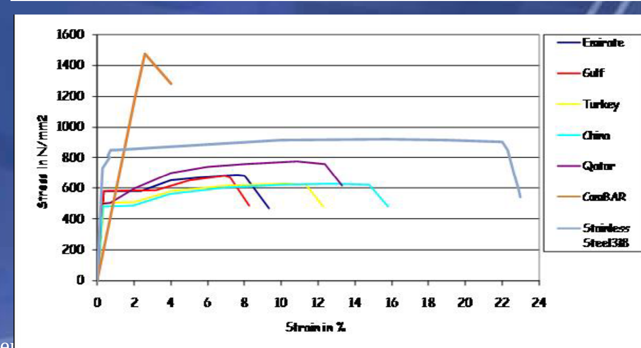
Future Research

Recycled Concrete Reinforced with GFRP Rebars

The mechanical properties of Recycled concrete reinforced with GFRP rebars is not well documented as there is little experimental testing of such concrete. Recent experimental testing of GFRP showed excellent tensile strength as well as superior durability. It is proposed to perform similar experiments to the one presented in this paper for the reinforced concrete beams. The results of these future tests will be compared with those obtained for carbon steel reinforcing bars.







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  - Emirates Recycling
  - Hi Star water Solutions (Dubai)
  - MB Mix
  - Uni Mix (Dubai)
  - Dubai Central Laboratory (DM)
  - Geoscience Testing Laboratory