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Properties of Sand-lime and Concrete Brick/Block Units Manufactured in Riyadh, Saudi Arabia

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ABSTRACT. A total of 330 concrete and 30 Sand-lime bricks/blocks along with representative sand and aggregate samples were collected from 24 brick/block factories in Riyadh, Saudi Arabia. Tests needed to determine the mechanical and physical properties for the collected specimens were carried out. These are: grading, specific gravity, absorption of aggregate and compressive and flexural strengths, modulus of elasticity, density and water absorption of bricks/blocks.

Reults of the study indicate that there is a wide variation in the mechanical properties of the collected specimens which are greatly influenced by the type of the raw materials used (white or red sand), mix proportions, curing conditions and manufacturing process. Also, based on the statistical analysis performed for the test results, empirical formulas that relate the flexural strength, modulus of elasticity, water absorption and density to the compressive strength of the bricks/blocks are suggested.

Masonry is normally constructed from mortar-bonded brick/block units of different materials, shapes and sizes. The common types of units are concrete, Sand-lime and clay bricks (solid, perforated, or frogged) or blocks (solid or cellular). The properties of the masonry vary depending on the properties of the unit used, (ACI-ASCE 1992).

The use of concrete blocks (CB) in building industry has increased in popularity over the last 30 years. Probably, the main advantage of the blocks over clay bricks is their higher productivity because they are normally six times larger in volume and their manufacturing process is easier and cheaper. Concrete blocks are either autoclaved or aerated, and manufactured with either lightweight or normal (natural) aggregate. They are being invariably manufactured solid, hollow or cellular. The manufacturing process of CB invovles compressing the freshly mixed constituent materials in a mold followed immediately by extrusion of the pressed block so that the mold can be used repeatedly. The mix proportions contain high fine aggregate and less cement resulting in high aggregates cement ratio and less cost. As in other concrete works, admixtures and cement replacement materials are sometimes used.

Sand-lime bricks (SLB) are suitable for use in both external and protected internal walling. They are available as facing bricks or as commons. The raw materials used for manufacturing the SLB are very fine siliceous aggregate, high-calcium lime and water. Inert and stable pigments are normally added to give the required color. The materials are first mixed in the required proportions and mechanically pressed into molds under considerable pressure. They are then cured in high pressure steam autoclaves for several hours which results in the combination of the lime with part of the siliceous aggregate to produce hydrous Sand-lime (tobermorite), which in turn, forms the binding medium in the finished bricks.

Unfortunately, in comparison with plain cement concrete, there are very few data available about the physical and mechanical properties of concrete and Sand-lime brick/block units such as compressive and flexural strengths, modulus of elasticity, density and water absorption. Although significant contributions on the study of these properties have been made internationally by a number of researchers, such results are still spares and represent only a small aspect of the overall performance of these units. There are, however, many other aspects that have not been considered. The type and quality of raw materials used in the mix, manufacturing process and curing methods are just some to exemplify. However, in Riyadh, Saudi Arabia, although CB and SLB are heavily used to construct the inner and outer masonry walls in reinforced concrete structures, there is no data available on the properties of the units produced and their quality for masonry construction.

This paper presents the first part of the research project concerning the properties of concrete and Sand-lime brick/block units produced in Riyadh. The properties considered in the study are the compressive and flexural strengths, modulus of elasticity, density and water absorption.

Survey and Test Program

A survey of the factories producing concrete and Sand-lime bricks/blocks was carried out. Forty six factories were visited. A total of 330 concrete blocks/bricks and 30 Sand-lime bricks along with the representative sand and coarse aggregates samples were collected from 24 different factories. It was thought that the specimens collected from these factories were representative of the bricks/blocks produced in all the located factories. Some details about the factories visited and the specimens collected are given in Tables 1 and 2.

Table 1. Particulars of the Sand-Lime brick units manufactured in Riyadh.

No.	Factory Name	Location	Mix Proportion lime:sand:water	Manufacturing process/pressure	Methods of curing	Type of sand	Type of Unit
L1	Arabian Co.	Alhayer	1:7.80:0.58	Auto/200 Bar	Autoclave	Red	Brick
L2	Saudi Sand Lime	Senaeyah	1:8.08:0.91	Auto/400 Bar	Autocalve	Red	Brick

Tests for the collected specimens which cover physical properties such as density and water absorption as well as mechanical properties such as compressive and flexural strengths were carried out as per ASTM-C67-93a. Modulus of elasticity was measured using PL-60 strain gauges and tested as per ASTM-E111 standards.

Absorption, specific gravity and the grading characteristics of sands and the coarse aggregates were also determined in accordance with ASTM-C67-93a standard.

Survey Observations

Data collected from various factories showed that varying methods of manufacturing are being practiced in Riyadh (see Tables 1 and 2). The manufacturing process varies from manual to fully automated one and from low to high molding pressure (0.1 to 400 bar). The raw materials used are red and white sands with crushed limestone corase aggregates. The curing conditions vary from water spraying, to normal and high pressure (autoclave) steam curing regimes. The mix proportions depend on the type of units produced. Some factories do not use fixed quantity of mixing water but leave it to the masons to decide. In general, most of the surveyed factories have no quality control process; some of them are

Table 2. Particulars of concrete block/brick units manufactured in Riyadh.

Factory design-ation	Factory name	Mix proportion cement:sand: agg:water	Manufacturing process/ pressure	Methods of curing	Type of sand	Type of unit
L3	Al-Mudifer	1:1.5:5.54: ---*	Auto/ 7.64 Bar	water spray	white	Brick
L4	Saudi Co.	1:0.71:2.14: ---	Auto/ 6.12 Bar-	water spray	white	Brick
L5	Boh Est.	1:1.82:6.82:0.48	Auto/160.00 Bar	water spray	white	Brick
L6	Saudi American	1:0.5:8:0.75	Auto/ 6.124 Bar	Autoclave & water spray	red	Block
L7	Jwaneb Factory	1:4:6: ----	Auto/ 71.35 Bar	water spray	white	Block
L8	Falwah Factory	1:1.74:3.68:0.5	Auto/**	water spray	white	Block
L9	Al-Yahya	1:1.74:3.46:0.19	Auto/ 6.8 Bar	water spray	white	Brick
L10	Al-Hajeri	1:3.57:7.14:0.64	Auto 80 Bar	Autocalve	white	Block
L11	Bin-Dayel	--------------------	Auto	Autoclave	white	Block
L12	Al-Rajhi	1:2.53:5.29:-----	Semi-auto	Autoclave	white	Brick
L13	Al-Hana	1:2.73:4.55:-----	Semi-auto	water spray	white	Brick
L14	Bumco Co.	1:2.22:4.44:-----	Auto	water spray	red	Block
L15	Tasum Co.	1:3.85:7.69:-----	Semi-auto/173.29	water spray	white	Brick
L16	Namlah	1:2.36:6.73:0.63	Semi-auto	water spray	red	Brick
L17	Est.	1:3.85:7.69:-----	Semi-auto/83.96	water spray	white	Block
L18	Al-Wafa Est.	1:3.75:6.25:-----	Semi-auto/	water spray	white	Block
L19	Al-Wadi	1:1.65:3.75:0.75	Semi-auto/	water spray	white	Block
L20	Al-Mohalib	1:2.78:7.22:0.5	Semi-auto	water spray	white	Brick
L21	Al-Shalhob	1:3.57:8.57:0.93	Semi-auto/	water	white	Brick
L22	Al-Wosta	1:2.33:7:0.67	Semi-auto/	spraywater	white	Block
L23	Encom	1:2.22:4.44:0.5	Semi-auto/	spray	white	Block
L24	El-Eid	1:2.85:8.57	Auto/	water spray	white	Block
L25	Al-Aziziah	1:2.66:8:---	Auto/	water spray	white	Block
L26	Ijzala	1:1.87:7.5:----	Auto/	water spray	white	Block
L27	Al-Zehor	1:3.12:7.5:----	Auto/	water spray	white	Block
L28	Al-Areth	1:1.5:6:0.4	Auto/	water spray	white	Block
L29	Al-Orija	1:2.77:6.11:0.46	Auto/	water spray	white	Block
L30	Al-Wadi	1:2.14:8.57:----	Auto/	water spray	white	Block
L31	Al-Borek	1:2.85:5.71:0.57	Auto/	water spray	white	Block
L32	Al-Garny	1:2.66:8:----	Auto/	water spray	white	Block
L33	Arth Al-Taiba	1:2.66:8:----	Auto/	water spray	white	Block
L34	Al-Jazerah	1:2.85:7.14:----	Auto/	water spray	white	Block
L35	Al-Jaserah	1:3.33:7.66:0.93	Auto/	water spray	white	Block
L36	Al-Jazerah	1:2.85:7.85:----	Auto/	water spray	red	Block
L37	Al-Rjehi	1:2.85:8.57:----	Auto/	water spray	white	Block
L38	Al-Metrek Co.	1:4:8.33:-----	Auto/	water spray	white	Block
L39	Shebh Aljezrah	1:3.84:8.46:-----	Auto/	water spray	white	Block
L40	Al-Bena	1:3.07:8.46:-----	Auto/	water spray	red	Block
L41	Al-Suliman	1:2.85:4.64:-----	Auto/	water spray	red/white	Block
L42	Al-Moudyfer	1:2.5:6.5	Auto/	water spray	red/white	Block
L43	Al-Ethad	1.2:2.5:7.5	Auto/	water spray	white	Block
L44	Al-Homidan	1:2.67:7.33	Auto/	water spray		Block
L45	Al-Rajhy	1:2.5:7.5	Auto/	water spray	white	Block
L46	Al-Samhan Saleh	1:2.35:7.05	Auto/	water spray	red	Block

* ---- = Undefined quantity of water. ** / = Undefined pressure.

producing very low quality concrete units. This was confirmed by the number of units broken during handling of the specimens in the factories.

Different types, sizes and shapes of units are produced. Some of the cited shapes are shown in Fig. 1. These vary from solid bricks to perforated brick/block units and cellular blocks. The height and length of the units, to some extent, are fixed at approximately 300 and 400 mm, respectively, while the width varies from 100 to 200 mm.

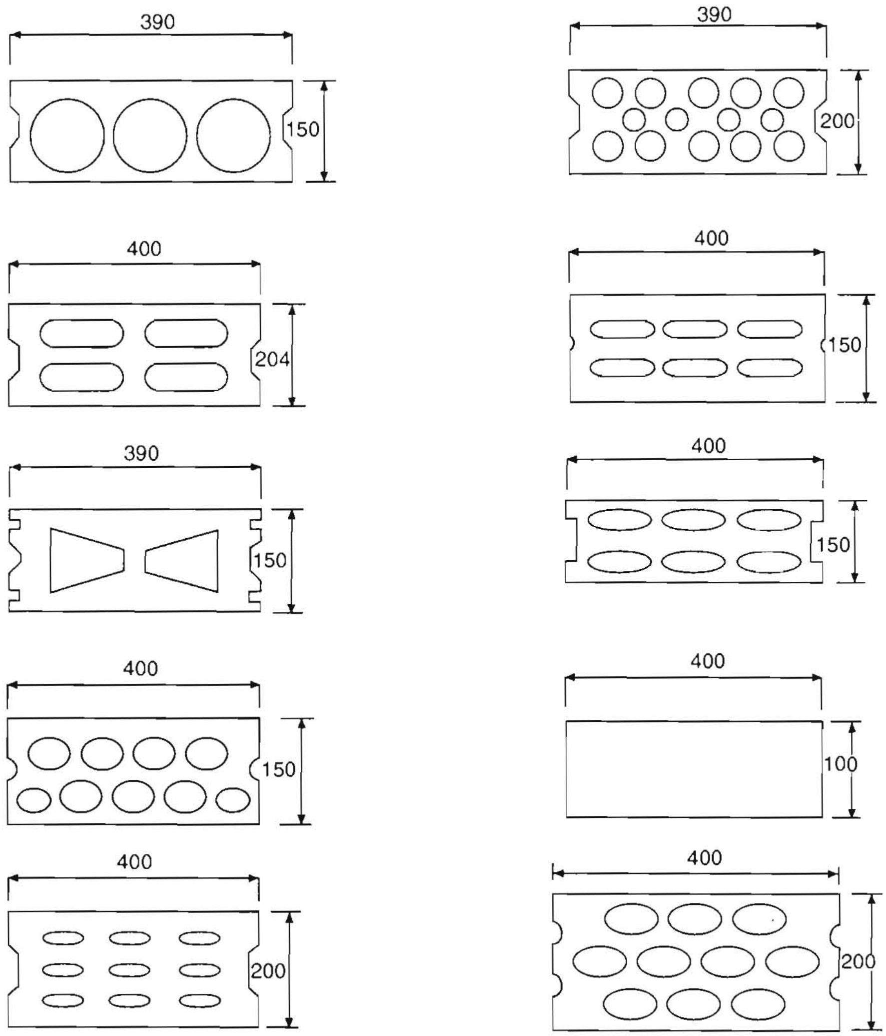

Fig. 1. Typical shape and dimensions of bricks/blocks collected from various factories.

In summary, as far as the production of CB and SLB units are concerned, different types of factories exist in Riyadh city which are producing different types of these units. While some of these factories are well established with fully automated plants, others are semi-automated and others are of open yard type. The factories are operated by semi-skilled or unskilled masons. More than seventy five percent of the located factories are using white sand in their production.

Test Results and Discussion

Sand and Coarse Aggregates

Typical results of sand grading, specific gravity and absorption are shown in Tables 3 and 4. It can be seen from the sieve analysis results that the red sand gradation is within the (ASTM-C33-1989) standard limits but the white sand is not.

Table 3. Grading of red and white sands.

Sieve size (mm)	Red sand % Passing	White sand % Passing	ASTM-C33 Limits
No. 4 (4.75)	100	100	95-100
No. 8 (2.36)	82	99.5	80-100
No. 16 (1.18)	54.5	97	50-85
No. 30 (0.6)	33.3	85.3	25.60
No. 50 (0.3)	18.4	42.6	10-30
No. 100 (0.15)	7.8	6.6	2-10
No. 200 (0.075)	1.26	1.0	0-3
Pan	–	–	–

Table 4. Specific gravity, fineness modulus and absorption of red and white sands.

Parameter		Red sand	White sand
Specific gravity			
a.	Bulk dry	2.52	2.51
b.	Bulk saturated	2.57	2.52
c.	Apparent	2.65	2.53
Water absorption %		2.03	2.44
Fineness modulus		3.01	1.9

The sieve analysis results also show that the white sand particles are finer than those of the red sand. This is also confirmed by the higher fineness modulus of the latter (3.01). The grain sizes, in both sands, range from pebble to silt. However, the red sand has higher specific gravity and water absorption than the white sand. This is due to the fact that the red sand particles are coated by clay and iron oxide. The high value of water absorption of the red sand indicates that it is more porous than the white sand.

Table 5. Grading of coarse aggregates.

Sieve size in (mm)	% Passing	ASTM C-33 Limits
1 (25.40)	97.6	90-100
3/4 (19.05)	73.2	90-100
1/2 (12.70)	11.9	25-55
No. 4 (4.75)	0.5	0-5

Table 5 shows a typical gradation of the coarse aggregates that is being used by the factories for the production of mortar and concrete units. The gradation shows that the percentages passing the 3/4" (19.05 mm) and 1/2" (12.70 mm) sieves are less than those specified by the ASTM-C33-1989 standard. Thus, the corase aggregates being used in the factories is coarse than the specified well graded one. Table 6 presents the specific gravity and water absorption of the coarse aggregates. It is worth mentioning here that the coarse aggregates that is currently being used in Riyadh is of crushed limestone type and is produced in quarries located around the city.

Table 6. Specific gravity and absorption of coarse aggregates.

Parameter		
Specific gravity		**Corase aggregate**
a.	Bulk oven dry	2.44
b.	S.S.D.	2.49
c.	Apparent	2.58
Water absorption %		2.35

Sand-lime Brick Units

Table 7 presents the properties of Sand-lime brick units. It was found that only two factories produced such type of units are L1 and L2 and both of them incorporated red sand in their products. Test results presented in Table 7 indicate that the mix proportions have an appreciable effect on the properties of the units. It seems, however, that the mix proportions (specially water-lime and sand-lime ratios) have more influence on the engineering properties of the units than the molding pressure. This is confirmed by the fact that although factory L1 uses lower molding pressure (see Table 1) than factory L2, the results shown in Table 7 indicate that the compressive strength, density and modulus of elasticity are higher for the units from factory L1. This is because the units from factory L1 have lower sand-lime and water-lime ratios as compared to those from factory L2.

The average stress-strain curves for the specimens collected from factories L1 and L2 and subjected to axial compression are shown in Fig. 2. The corresponding load-strain curves for the specimens from the same factories subjected to flexural tests are shown in Fig. 3.

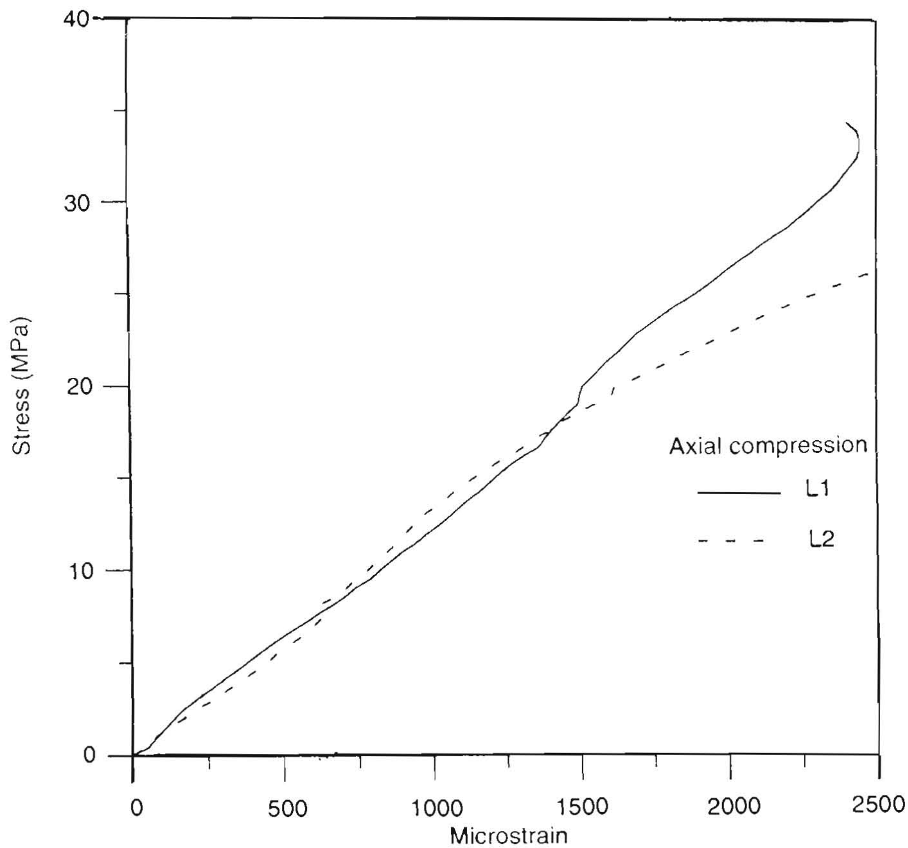

Fig. 2. Typical compressive stress-strain relationship of Sand-lime bricks.

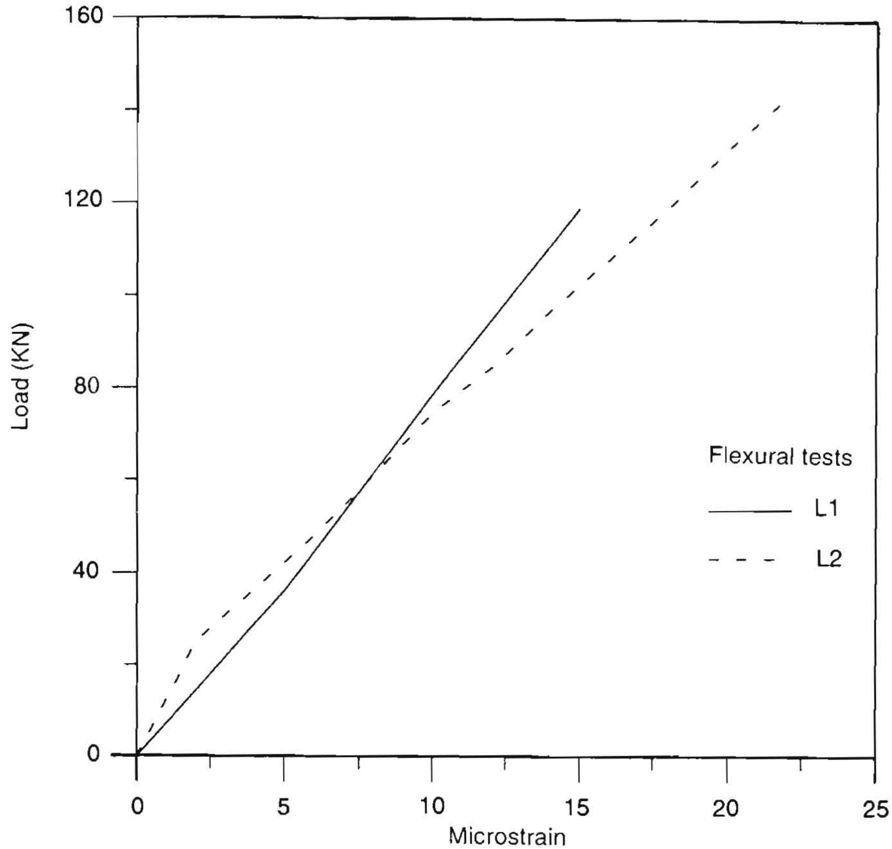

Fig. 3. Typical load-strain relationships of Sand-lime bricks subjected to flexural test.

Table 7. Properties of collected Sand-lime bricks.**

Factory designation	Compressive strength* (MPa)	Modulus of elasticity (GPa)	Water absorption (%)	Density (gm/cm^3)
L1	33.5	13.2	15.2	1.9
L2	25.1	12.3	16.3	1.8

* based on the net area of the bricks.
** results are average of three specimens.

Of interest to mention at this point is the fact that, although the materials used by the two factories were identical and, in most cases, the usage for the units would be the same, the test results given in Table 7 show appreciable differences in the engineering properties of the units collected from the two factories, the units L1 being superior to L2. Such differences can be attributed to the mix proportions (see Table 1), particularly the water-lime ratio.

Table 8. Properties of collected concrete units.**

Specimen No.	Compressive strength* (MPa)	Flexural strength (MPa)	Modulus of elasticity (GPa)	Water absorption (%)	Density (gm/cm^3)
L3	16.2	1.26	22.0	5.5	2.33
L4	10.7	1.5	17.9	6.1	2.4
L5	7.4	1.3	11.8	6.2	2.4
L6	20.3	0.82	18.8	6.3	2.23
L7	10.6	1.2	14.3	6.8	2.3
L8	9.1	1.9	15.0	6.7	2.4
L9	16.1	1.6	41.4	5.3	2.3
L10	20.5	3.2	29.0	5.7	2.33
L11	12.8	2.7	17.2	5.3	2.5
L12	16.2	2.9	28.9	5.1	2.3
L13	11.8	2.6	18.0	5.5	2.4
L14	8.0	1.2	12.3	8.6	2.4
L15	10.0	1.8	22.2	5.98	2.35
L16	7.5	1.3	18.1	7.6	2.4
L17	11.6	1.8	10.5	5.9	2.4
L18	15.0	2.1	26.8	6.0	2.3
L19	9.9	1.6	31.4	5.5	2.5
L20	8.6	2.1	17.4	6.1	2.4
L21	6.7	1.7	18.6	6.2	2.4
L22	13.4	2.6	15.2	6.3	2.4
L23	7.6	1.7	14.4	5.6	2.3
L24	24.9	2.7	25.1		

* based on the net area of the unit. ** results are average of three specimens.

Concrete Units

Table 8 presents the average test results of the compressive and flexural strengths, modulus of elasticity, water absorption and density for concrete units that were collected from the remaining twenty two factories. The results show wide variations in the compressive strength of the concrete units, f'_{cb}. It varies from about 6 to 25 MPa. Since the mix proportions are mainly selected by each factory and, to some extent, in a random manner, it was difficult to arrive at a firm conclusion about the specific effect of using red or white sand on the properties of the concrete units.

For example, while there is only a little difference between the mix proportions for the bricks collected from factory L16 (utilising red sand) and that of the blocks collected from factory L22 (utilising white sand). The results shown in Table 8 reveal that the average f'_{cb} of the white sand specimens (L22) is about twice as much as that of the red sand specimens (L16). This indicates that white sand produces concrete units with higher f'_{cb}. Contrary to this, the results of the specimens L16 and L23 show that, although the white sand specimens (L23) have lower aggregate-cement and water-cement ratios, as compared to the red sand specimens (L16), the compressive strength of these specimens are nearly the same. Moreover, the results of the specimens L22 and L23 (both of white sand) show that the L22 specimens having higher aggregate-cement and water-cement ratios have higher compressive strength (above 60%) than that of L23 specimens with lower aggregate-cement and water-cement ratios. These inconsistencies are probably due to the quality control in the factories themselves which varies from factory to factory. Results in the same table also show that there is almost a consistent trend that modulus of elasticity, E, of white sand units is greater than that of the red sand ones. Furthermore, the results show that the water absorption of the white sand concrete units is consistently smaller than that of the red sand units. This can be attributed to the fact that water absorption of the white sand itself is less than that of the red sand.

Table 8 also shows that the differences in the density of all the specimens are too insignificant to be considered. Considering the fact that there are wide variations in the mix proportions and water content of the specimens, and that the methods of manufacturing and curing are also different, the density being varied from a minimum of 2.23 to a maximum of 2.50 g/cm^3 could be considered as constant.

Typical axial stress-strain relationships for concrete units are shown in Fig. 4. The relationships show, as expected, non linear behavior and wide variations in the stress-strain relationships. Wide variations in the mix proportions, sizes and shapes of the units are the major causes for such inconsistent behavior.

Several researchers stated that the modulus of elasticity for concrete units is directly related to the compressive strength. Sahlin (1971) recommended to use the relationship.

$$E = K\ f'_{cb} \qquad (1)$$

where E = modulus of elasticity of concrete unit.
K = constant ranging from 500 to 1500, with a mean value of about 1000.

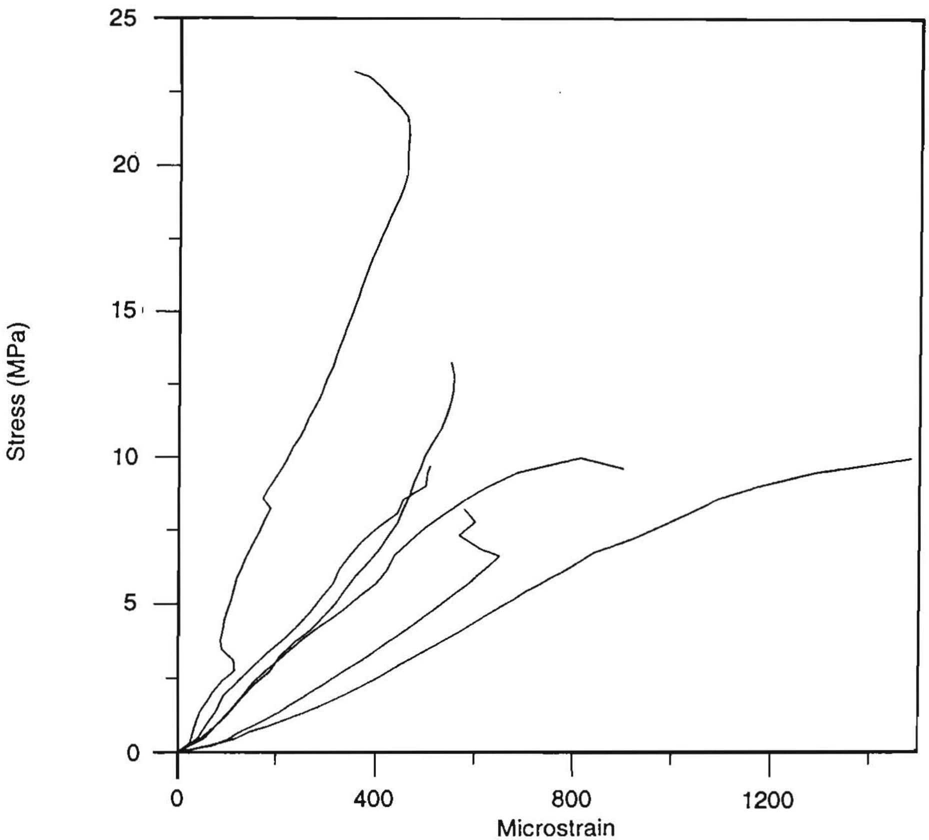

Fig. 4. Typical axial compressive stress-strain relationship of concrete bricks/blocks.

Colville and Hendry (1978) stated that, for E at 0.33 f'_{cb} for concrete unit with compressive strength ranging from 10.5 to 12.5 MPa, the constant K could be 580. However, no value for K was suggested for concrete units with higher f'_{cb}.

The measured moduli of elasticity for both the red and white sand concrete units test specimens are plotted against the square root of the compressive strength and presented in Fig. 5. Due to limited number of the red sand units, the statistical analysis performed on the white sand units results only shows that the relationship between E (GPa) and f'_{cb} (MPa) can be expressed as:

$$E = 5.92 \sqrt{f'_{cb}} \qquad (2)$$

The constant K = 5.92 in Equation (2) has higher value than K = 4.73 recommended for concrete by ACI (1995) building code equatoin 8.5.1 by about 25% when converted to SI-units. This could be, as indicated earlier, due to the variation in the mix proportions.

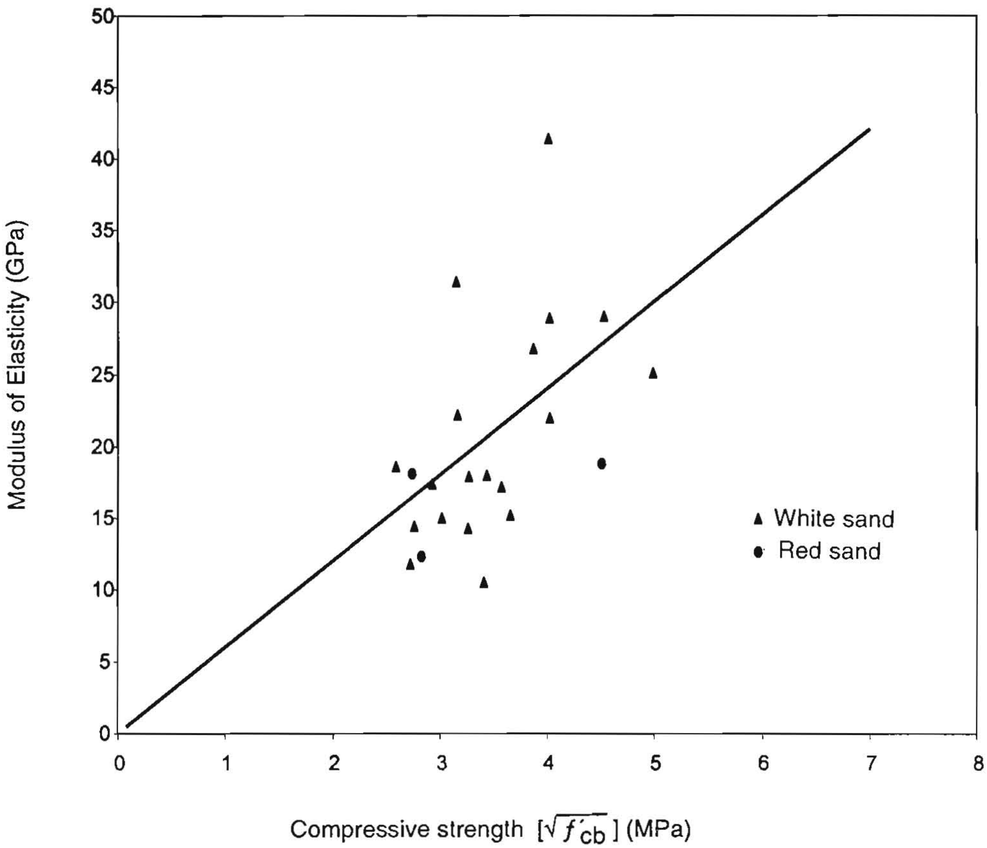

Fig. 5. Relationship between modulus of elasticity and compressive strength for concrete bricks/blocks.

The load-strain relationship of concrete units subject to flexural tests under central point loading is shown in Fig. 6. During testing, two types of failure modes were observed: shear and flexural modes. As is evident from this figure, the shape of the load-strain curve as well as the ultimate load and ultimate strain were greatly influenced by the mode of failure.

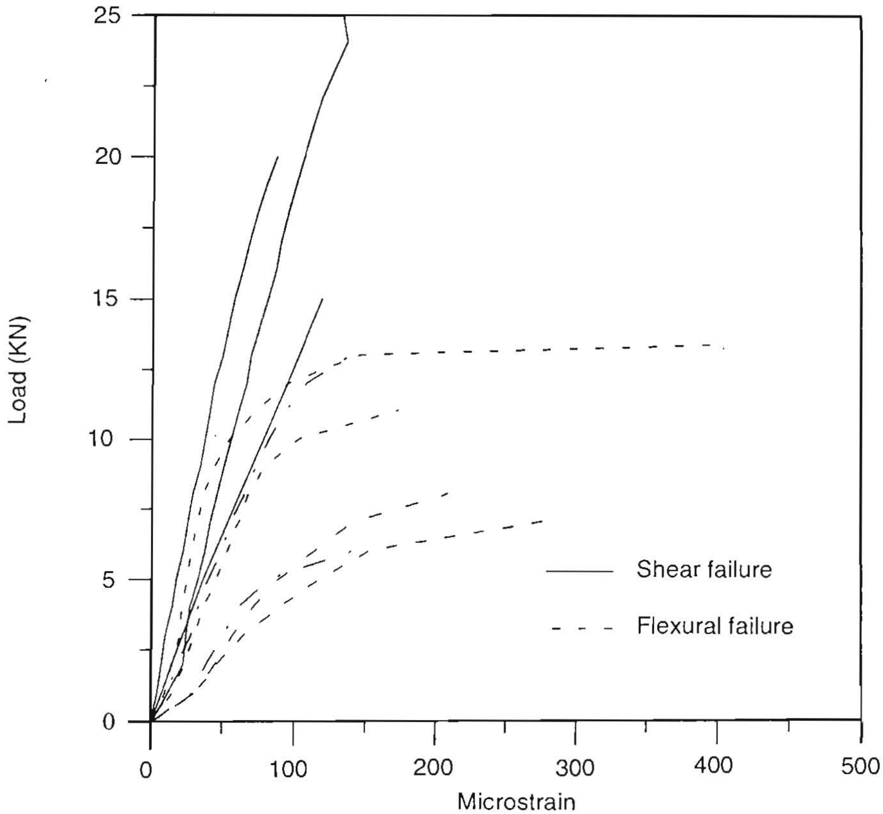

Fig. 6. Typical load-strain relationships for concrete blocks subjected to flexural test.

Fig. 7 shows the relationship between the compressive and flexural strengths of the concrete units. Also, the statistical analysis carried out on the results of the white sand units show that the relationship can be expressed as:

$$f_{tb} = 0.57 \sqrt{f'_{cb}} \qquad (3)$$

where f_{tb} = flexural strength of concrete unit in MPa.

The constant 0.57 lies between 0.50 and 0.62 used, respectively, in equations (11-11) and (9-9) of 1995 ACI building code when converted to SI-Metric equivalent values with f_{tb} and $\sqrt{f'_c}$ expressed in MPa. It can be concluded that the prediction of both modulus of elasticity and flexural strength of concrete brick

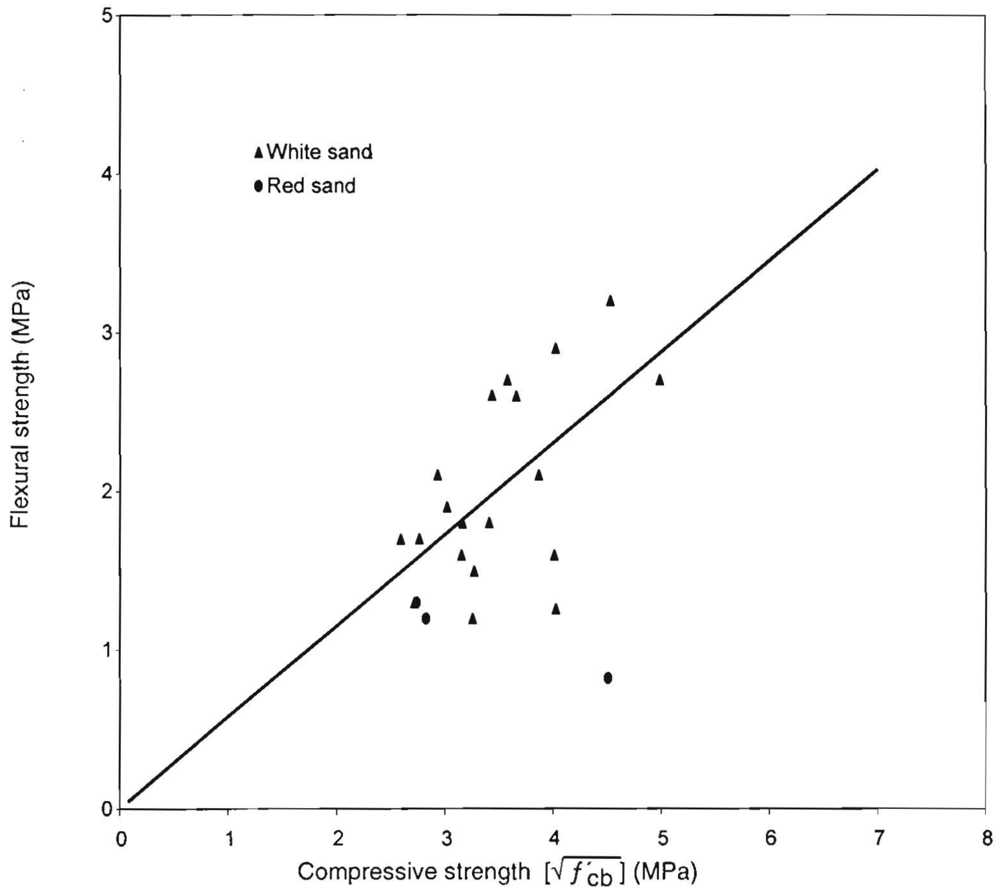

Fig. 7. Relationship between flexural strength and compressive strength of concrete bricks/blocks.

/block units manufactured in Riyadh can be safely carried out using ACI code formulas.

The relationship between both water absorption and density and f'_{cb} are shown in Figs. 8 and 9 respectively. The results indicate that both the water absorption and density of the concrete units decrease with the increase in the compressive strength. Statistical analysis carried out using the test results show that water absorption (W) and density (ρ) of the concrete units are related to f'_{cb} such that:

$$\text{Ln } W = -0.01 f'_{cb} + 6.63 \quad (4)$$

and

$$\text{Ln } \rho = -0.003 f'_{cb} + 2.45 \quad (5)$$

where W in %, ρ is in gm/cm³ and f'_{cb} in MPa

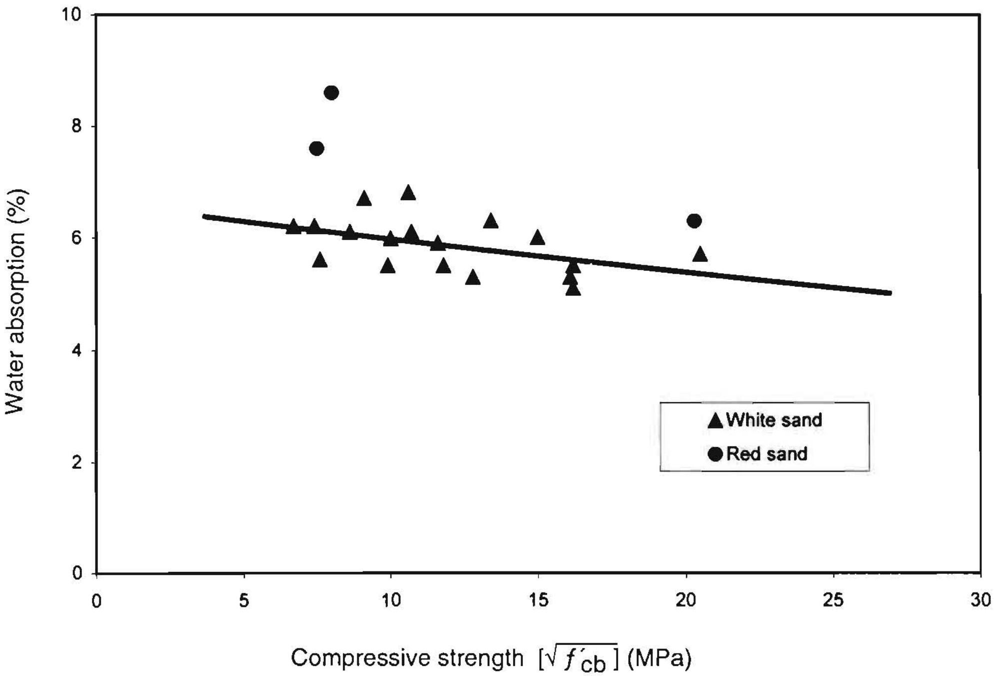

Fig. 8. Relationship between water absorption and compressive strength of concrete bricks/blocks.

It was intended to compare the proposed relationships with those proposed by other researchers. Unfortunately, although an exhaustive literature survey was conducted, none became available. Tardos *et al.* (1992) conducted some comparisons between the masonry units produced in different factories belonging to thirty three national associations of European, Asian and African countries, but no relationships between different engineering properties of concrete units were discussed.

Conclusions

Based on the survey of the construction sites and factories located in Riyadh, Saudi Arabia and on the test results of laboratory some conclusions can be drawn and summarised as follows:

1. White sand particles are finer than those of red sand. While the red sand satisfies the grading requirements of ASTM C33, the white sand is not well graded and does not conform with the ASTM C33 limits.

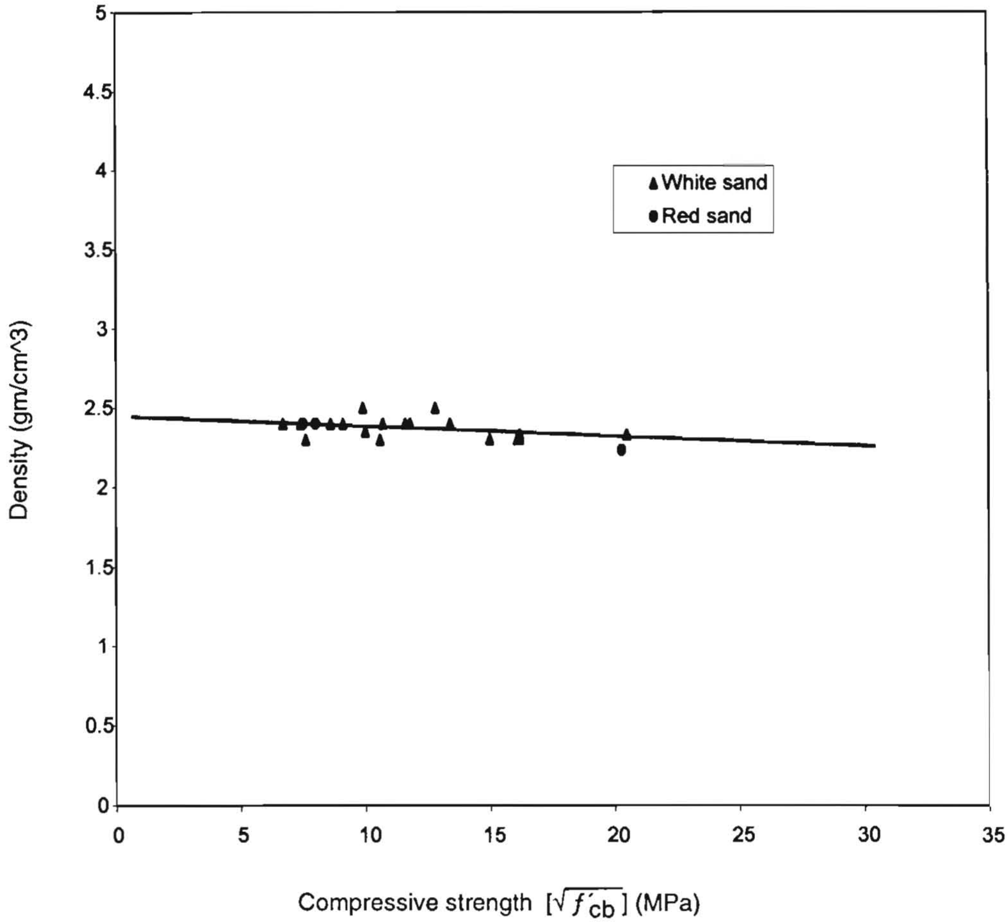

Fig. 9. Relationship between weight and compressive strength of concrete bricks/blocks.

2. Different types of concrete blocks/bricks using different raw materials and mix proportions are currently produced in Riyadh.
3. The physical and mechanical properties of brick/block units are affected by the type of raw materials, mix proportions, curing conditions and manufacturing process.
4. Concrete units incorporating white sand have higher modulus of elasticity as well as lower water absorption than those manufactured with red sand.

5. Modulus of elasticity and flexural strength of concrete block/brick units manufactured in Riyadh are related to the square root of the compressive strength by equation 2 and 3 . They can be predicted safely interms of compressive strength using the appropriate equations given in the ACI code for plain normal weight concrete can be predicted using ACI code method.
6. Water absorption and density of concrete block/brick units are related to square root of compressive strength in natural log. based formulas which are given by equations 4 and 5, respectively.

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خواص الطوب الجيري والخرساني المنتج في مدينة الرياض ، المملكة العربية السعودية

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تم أخذ ٣٣٠ عينة من الطوب الخرساني و ٣٠ عينة من الطوب الجيري مع عـينات للرمل والركـام من مـصـانع الطوب بمدينة الرياض . وتم إجـراء الفحوصات المخبرية اللازمة على هذه العينات والتي منها التدرج الحبيبي وخصائص الامتصاص والكثافة النوعية للرمل والركام ومقاومة الضغط والإنحناء ومعامل المرونة والكثافة والإمتصاص لعينات الطوب والطابوق .

بين البحث بأن التدرج الحبيبي للرمل الأبيض لا يتوافق مع المواصفات الأمريكية ولقد وجد بأن معامل النعومة للرمل الأبيض والأحمر ٩ , ١ و ٠١ , ٣ على التوالي ، وأن الوزن النوعي ومقدار الإمتصاص للرمل الأحمر أكبر من الرمل الأبيض .

كما دلت النتائج على وجود إختلافات كبيرة في الخواص الميكانيكية للطوب والطابوق الخرساني والجيري وكان ذلك بسبب تأثير استخدام المواد الخام (رمل أبيض ، رمل أحمر) ، طريقة المعالجة والتصنيع . وباستخدام التحليل الإحصائي لنتائج الفحوصات المخبرية لعينات الطوب الخرساني تم إقتراح علاقة بيانية بين كل من مقاومة الإنحناء ومعامل المرونة والإمتصاص

والكثافة النوعية مع مقاومة الضغط .

وخلص البحث بأنه يمكن حساب معامل المرونة وقوة القص للطوب الخرساني المنتج بالمملكة باستخدام العلاقة المستخدمة في الكود الأمريكي (ACI) .