The use of X-ray diffraction and field inspection to detect risky aspects in construction materials; crushed stones and reinforcing steel

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This paper aims to identify two risky problems that may affect the integrity of concrete structures. On the one hand, crushed stones from carbonate rocks used nowadays as coarse aggregate in concrete have to meet a number of specifications relating to different aspects including alkali reactivity. However, standard tests for alkali-carbonate reaction require one year-period and hence are impracticable during construction. On the other hand, the performance of steel during fabrications on site may display undesirable signs despite of meeting specified grades and ductility assessment based on standard tests. The first phase of the study deals with crushed stones from eight sources; six pink-lime stones and two dolomites, of which four types are examined using X–Ray diffraction analyses (XRD). Petrographic examinations (PGE) and microscopic inspection are also incorporated. Results indicate that concrete strength attained using all crushed stones are relatively comparable providing other variables are similar. However, results of XRD supported by PGE indicate the presence of the mineral 'Ankerite', which has expansive properties, in the tested dolomites quarried from Suez area. Up to 18% ankerite is recorded and may hence lead to concrete deterioration. The second phase of the study examines reinforcing steel from two providers. Both products meet the requirements of Egyptian Code and relevant standard for grade 400/600 regarding mechanical and chemical properties, and ductility assessment. But, while being bent to form reinforcement on sites, critical unexpected cracks are developed at the corners of many steel bars delivered from the two providers. Such unseen steel defects in foundations and pile caps may lead to serious issues. This finding indicates that a common arrangement of cold-bend test is not totally reliable as a qualitative measure for ductility of reinforcing steel. The consequences of the above two aspects may lead to serious safety problems. Technical recommendations to detect the two aspects are proposed.

يهدف البحث الي كشف نقطتين قد تؤثران سلبيا علي المنشآت الخرسانية، الأولي تتعلق بكسر الأحجار الكربوناتية المستخدمة كركام كبير في الخرسانة والتي يلزم أن تحقق خصائصها للعديد من المتطلبات ومنها النشاط القلوي. ولكن إختبار التفاعل القلوي الكربوني يستلزم عام كامل ويكون غير ملائم أثناء الانشاء. كما أن أداء أسياخ التسليح أثناء تشغيلها في الموقع قد يظهر نتائج غير مرغوبة رغم أن نتائج اختباراتها تحقق متطلبات الرتبة المطلوبة والممطولية. وعلي ذلك فقد اشتمل البحث علي جزئين تضمن الأول دراسة ٨ أنواع من كسر الأحجار الكربوناتية منها الحجر الجيري الوردي من ٦ مصادر بالاضافة الي الحجر الدولوميتي من مصدرين. وتم اجراء اختبار الأشعة السينية المتفرقة والاستعانة بالفحص البيتروجرافي وكذلك الميكروسكوبي. ورغم أن مقاومات انضغاط الخرسانة المصنوعة من مختلف أنواع الركام متقاربة مع ثبوت باقي المتغيرات فقد أظهرت نتائج الأشعة السينية المتفرقة والفحص البيتروجرافي وجود معدن "الأنكريت" ذو خاصية التغبر الحجمي بنسبة تصل الي ١٨% في نوعي الدولوميت المستخرجة من منطقة السويس مما قد يؤدي الي تدهور الخرسانة. وتضمن الجزء الثاني من البحث دراسة عينات حديد تسليح من مصدرين. ورغم أن اختبارات كلا النوعين حققت متطلبات الكود المصري والمواصفات المصرية لرتبة ٦٠٠/٤٠٠ فقد ظهر عند تشغيل نوعي الحديد في موقعي عمل شروخات غير متوقعة في أركان العديد من الأسياخ. وتدل هذه النتائج أن احدي الطرق الشائعة لاجراء اختبار الثني علي البارد لا يمكن الاعتماد عليه كليا كمقياس كيفي لممطولية حديد التسليح في الموقع. وهذه العيوب في أركان الحديد قد لا تلاحظ في الموقع وتؤدي الي مشاكل حقيقية في الأساسات وهامات الخوازيق. وتوصل البحث الي توصيات لكشف النقطتين موضوع الدراسة المتعلقتين بكسر الأحجار الكربوناتية وحديد التسليح لتلافي عواقب تؤثر جديا علي أمان المنشأ.

Keywords: X-ray diffraction, Dolomite, Ankerite, Concrete cracks, Reinforcement, Ductility

1. Introduction

The safety of new construction relies on several factors including safe design, proper execution, and the use of proper materials in reinforced concrete. Actually, the term “proper materials” means to most engineers performing periodic traditional tests on

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concrete ingredients and reinforcing steel. These tests may include particle size distribution and determination of amounts of fine materials (% less than 80 μm) for aggregate, mechanical and physical tests to cement, and tension test to reinforcing steel to verify its mechanical performance and grade in addition to the so-called 'cold bend test' as a qualitative measure of ductility. In some projects, additional tests may be required such as chemical analyses for aggregates to ensure that the contents of chlorides and sulfates are within the permissible limit specified by the Egyptian Code (ECS 203, 2007) [1], chemical analyses for cement's sample to get the different oxides percentages, and for steel's sample, as well. From general prospective the prime concern in most constructions is always to achieve the required concrete strength considered in design with a lesser cement content just as specified in the project's specification. On the other hand, reinforcing steel from known source has to satisfy the steel grade considered in the design and if so steel type is always thought to be reliable. The performance of reinforcing steel during reinforcement fabrication on site may display undesirable signs.

2. Risky aspects

2.1. Coarse aggregate

Most problems in practice are currently associated with crushed stone that is commercially referred to by the Arabic term "Sen". This term is currently used in the area of construction referring to coarse aggregate in concrete regardless its reality whatever it means; dolomite (from the dolomite group) or crushed lime stone (from the calcite group), or even pink lime stone that is well-known in Alexandria and northern cost.

Actually, the intentions of consultants are always to follow numerous standard tests to ensure that used aggregates meet a number of specifications relating to mechanical performance, durability, grading, shape and size, chemical stability, resistance to fragmentation, and presence of harmful materials. However, alkali reactivity are not given due importance in most cases. In fact, the presence of some minerals in the used crushed stone despite being harmful to concrete is frequently unknown.

Reviewing literature indicates that the effect of types and properties of coarse aggregate on short/long-term performance of concrete have been studied by numerous researchers worldwide. For example, in a recent paper published by Badawy et al. [2], dolomites obtained from different sources in Egypt were examined as coarse aggregate in normal strength concrete. Variable studied were effects of aggregate type, washing of aggregate before mixing, curing regime, nominal maximum aggregate size, and different specimen sizes and shapes. They have concluded that the effect of dolomite washing on the compressive strength of concrete varied from marginal in the obtained dolomite from Alexandria to significant for concrete made of Kilo 101 dolomite. However, the authors based their comparison between aggregate types only on the achieved concrete compressive strength whereas aggregate reactivity was not concerned.

However, reactive aggregates were recognized by other researchers. Actually, history of alkali–aggregate reactivity indicates two types of reaction; the first discovered, and the most serious, is the alkali–carbonate rock reaction, which is mainly found with some carbonate rocks whereas the second type and most widespread is the alkali–silica reaction, which is found with a wide variety of silica rocks and minerals [3]. According to Dubberke [4], deterioration in concrete pavement was encountered when reactive dolomite aggregates were used in the mix. They have concluded that defects could only be observed in cores taken from newer concrete while there would be no surface cracks until concrete broke through. Also, much of the concrete in Barryfield Barracks in Canada had suffered from harmful reactive aggregate within two years of construction where concrete had been severely cracked [3]. It has been reported that the alkali-carbonate reaction due to the use of harmful aggregate was responsible for this damage. Rogers et al. [3] have reported that the use of low-alkali cement or the presence of fly ash as a partial replacement of cement by weight might significantly reduce the alkali-aggregate reaction of reactive coarse aggregate. In fact, the use of supplementary cementing materials as a partial replacement of cement by weight has not been well recognized in construction industry in Egypt.

Clearly, general agreement does exist in the literature on the consequences of using harmful reactive aggregate in many constructions everywhere. Actually it is so difficult and impractical, during construction to identify harmful aggregate with respect to carbonate reactivity using the long-term expansion test of rock cylinder in accordance with the standard ASTM C 586 [5] and Egyptian guide for experimental tests on concrete materials [6] where a one year-period is required.

From a general prospective, crushed stone is always produced in a crushing plant using primary and secondary crushers to crush rocks to the required sizes ranges. Rocks are produced from quarries where either bulldozer or jackhammer or both methods, as well, are used to crush the rocks to smaller sizes. The rocks involve many minerals; where the types relevant to this subject are ‘dolomite’, ‘calcite’, ‘quartz’, and ‘ankerite’. The crushed limestone is mostly calcite with lesser quartz, while crushed dolomite is mostly dolomite with very lesser calcite. The tricky problem here may appear from the presence of the unidentified mineral 'ankerite' in coarse aggregate. Actually, the carbonate rocks consist essentially of dolomite, calcite, and ankerite [7].

What is 'Ankerite'?

Ankerite is named after Professor M. J. Anker, an Austrian mineralogist. It is a member of the dolomite group of minerals. In fact, the dolomite group of minerals includes both dolomite; that is calcium-magnesium carbonate '$CaMg(CO_3)_2$' and Ankerite; that is calcium-iron-magnesium carbonate '$Ca(Fe. Mg)(CO_3)_2$'. The formula for Ankerite is also sometimes written as '$Ca(Fe. Mg. Mn)(CO_3)_2$' since there is actually a significant amount of magnesium and manganese substitution for the iron [8]. The structure of ankerite consists of alternating layers of carbonate groups (CO_3) and layers of metal cations. The cation layers alternate between calcium and iron. This alternation has the effect of lowering the symmetry of the crystals. Without this ordered alternation of metal ions, ankerite's symmetry would be the same as calcite's symmetry. In fact, dolomite and ankerite are very similar in many ways and are often confused for each other; however ankerite is usually denser, thicker and more deeply colored than dolomite.

Extensive studies related to the subject were conducted elsewhere. Research published by Dubberke and Marks [9] has also shown that the type of coarse aggregate used in concrete pavement was the major cause of premature deterioration of concrete. Their results indicated that the iron substitution for magnesium in the dolomite crystal was associated with the instability of the ferroan dolomite aggregates in concrete. They reported that two mechanisms contributed to the deterioration; the first was a bad pore system while the other was apparently a chemical reaction. According to Gillott and Swenson [10], the presence of iron (Fe) substituting for Mg in the dolomite crystal lattice was responsible for the instability of such dolomite.

In a very recent document reported by Ostrooumov in 2009 [11], the effective use of X-Ray Diffraction analysis (XRD) to examine the deterioration of historical monuments in Mexico has been reported where forty-three samples of volcanic rocks were studied. The analysis indicated the identification of several new mineral formations such as sulfates and carbonates in the rocks samples that might be responsible for the deterioration occurrence. Islam et al. [12] also used X-ray diffraction analysis to find the major constituents present in mineral aggregates. Actually, the efficiency of XRD measurement as an effective tool to characterize different concrete material ingredients has been recognized by many researchers (Tanaka et al. (2004) [13], Shehata et al. (2008) [14], Jaouadi et al. (2009) [15]).

From another prospective, PetroGraphic Examination (PGE) may be also very useful related to the discussed subject. A petrographic microscope is a type of optical microscope that can effectively be used to identify rocks and minerals [7]. Actually, it can be used to identify minerals and observe a series of their characteristics which reflect their properties. However, size of minerals that allows for optical identification is not smaller than 0.010 mm [16].

In fact, XRD and PGE are not given due attention in the local market although they remain the most valuable tests for predicting the overall performance of concrete aggregates in service. It is strongly believed that XRD supported by PGE are reliable and time-slight tools to detect the presence of harmful minerals such as ankerite when using crushed stone from carbonate rocks as coarse aggregate. It should be pointed out that tests required by the code for alkali carbonate reaction for aggregate require one year-period.

2.2. Steel reinforcement

The assessment of steel bars for being used as reinforcement in concrete structures relies mainly on the evaluation of their tensile behavior. According to valid standards [1], steel bars are classified to different grades. For instance, steel of grade 400/600 means that yield and ultimate strengths exceed 400 MPa, and 600 MPa, respectively, whereas elongation at fracture exceeds 14%. Also, the ductility of steel for concrete reinforcement can be defined as an ability to achieve significant deformations without marked increase of stresses beyond the yield strength of steel [17]. Ductility of steel is essential for the fabrication of reinforcement on site and also to get adequate performance of concrete structures under lateral loadings. For defining safe minimum values of ductility, it is first necessary to develop reliable ductility measurements. Most standards believe that cold-bend test is a consistent qualitative measure of ductility. This test is frequently required by engineers for testing steel used in building constructions.

According to ASTM A615M [18], “the bend test specimen shall withstand being bent around a pin without cracking on the outside radius of the bent portion”. The steel bars should be free of detrimental surface imperfection. The minimum bend diameter should be related to the diameter of bar being bent [19]. The required sizes of pins or mandlers are given in tables 1 and 2.

The main significance of the aforementioned bend test is to evaluate the ductility of steel bars as evidenced by their ability to resist cracking during bending. The test may be performed in different ways. Bending forces are applied through one of the three general arrangements illustrated in fig. 1 [20]. When complete fracture does not occur, the convex surface of the bent specimen is examined for cracks. It is of highly importance to state that results obtained by the three arrangements may not be exactly the same as noted by ASTM E0290 [20].

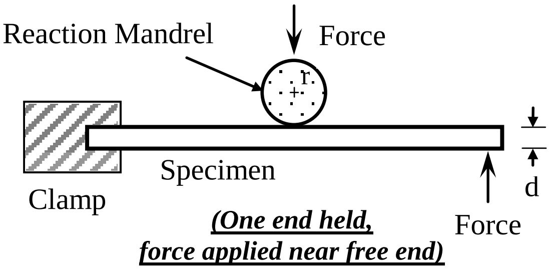
From another prospective, some types of reinforcing steel recently introduced in the Egyptian market may show scatter in material's mechanical properties. Actually, sources of that imported steel are designated only by country origin and therefore require more attention when used in construction.

Table 1
Cold-bend test requirements (ASTM A615M [18])

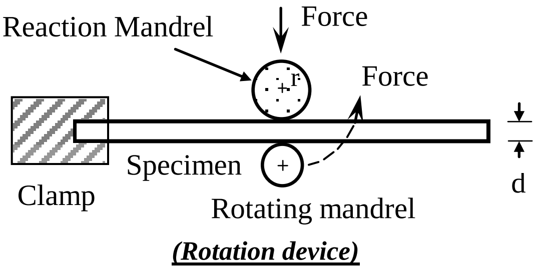
Bar nominal diameter d_b, mm	Pin diameter for bend test (180°)		
	Grade 300	Grade 420	Grade 520
10 mm to 16 mm	3.5 d_b	3.5 d_b	---
19 mm	5 d_b	5 d_b	5 d_b
22 mm to 25 mm	---	5 d_b	5 d_b

Table 2
Cold-bend test requirements (Guide for testing - ECS 203 [6])

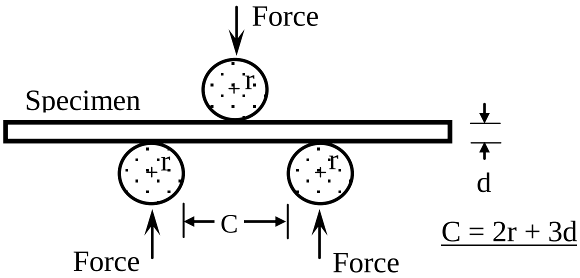
Bar nominal diameter d_b, mm	Pin diameter for bend test (180°)			
	Grade 240/350	Grade 280/450	Grade 360/520	Grade 400/600
Up to 25 mm	2 d_b	2 d_b	---	---
> 25 mm	3 d_b	3 d_b	---	---
Up to 20 mm	---	---	4 d_b	---
> 20 mm up to 36 mm	---	---	5 d_b	---
Up to 20 mm	---	---	---	4 d_b
> 20 mm up to 25 mm	---	---	---	5 d_b
> 25 mm up to 36 mm	---	---	---	6 d_b



(a) Semi-guided-bend test 'Arrangement A'



(b) Semi-guided-bend test 'Arrangement C'



(c) Guided-bend test

Fig. 1. Different arrangements for bend test according to ASTM E0290 (2006) [20].

3. Research significance

This research focuses on two completely different risky aspects associated with using nonconforming materials in concrete construction; coarse aggregates and reinforcing steels. The unintentionally use of crushed stone that contains harmful materials may lead to serious problems. Some crushed stones, that is essentially carbonate rocks, react with the alkaline pore solution in concrete, and sometimes produces harmful expansion leading to concrete cracking and deterioration. The presence of a certain amount of reactive material such as ankerite in the aggregates may create this problem. Under such circumstances, the developed cracks reduce concrete durability drastically and also result in increased chloride penetration to the reinforcing steel. Actually, it is of highly importance to properly recognize potentially reactive aggregates prior to construction, since there is no way of preventing the reaction after placing concrete. Test specified in most codes and standards for alkali–carbonate reaction requires a one year-period. Therefore, despite being not given attention by most engineers, XRD may be a very effective and time-slight tool to detect ankerite in crushed stones. The other risky aspect is related to the ductility of reinforcing steel. The well-known cold-bend test is frequently required by engineers for testing steel used in building constructions to ensure ductility level. Some arrangements of this qualitative test may not be usually adequate to represent real fabrication on site. A certain type and size of steel bars may crack during fabrication on site despite being passing the cold-bend test. The two aspects mentioned above are critically assessed in the current work. Although these aspects are unrelated to each other, they may ultimately lead to one end. Utilizing reactive crushed stones may cause premature concrete deterioration, whereas the use of unnoticeable cracked reinforcement may lead to unsafe concrete sections.

4. Experiments

The materials investigated in the present work are crushed stones from eight unlike sources in addition to steel bars, market products, from two different steel manufacturers. On the one hand, two types of the crushed stones were mainly dolomites quarried from Suez area whereas the remaining types are mainly calcite from Alexandria area. Eight materials are indicated as 'A' and 'B' for dolomites and from 'C' to 'H' for pink lime stones. It should be emphasized that the examined crushed stones are nowadays used as coarse aggregates in several concrete constructions. Fundamental tests involved include crushing value, percentage of materials finer than 80 µm, sieve analysis, chlorides and sulfates contents, and soundness. Out of the eight types of coarse aggregates, four selected types; two dolomites ('A' and 'B') and two pink lime stones ('C' and 'D'), are examined using XRD, of which one type was also examined by PGE. Microscopic examinations were also introduced for comparative purposes. The presence of ankerite in crushed stones is of prime concern. Concrete was made following the mixes given in Table 3 incorporating the eight subject coarse aggregates. Since concrete strength is not of primary concern in this work, concrete cubes were cured then tested at the age of 7 days. Ranges for obtained concrete compressive strengths are also given.

Table 3
Typical Concrete mix proportions and concrete strengths

Type of coarse aggregate	Concrete Ingredients per cubic meter of concrete						7-day comp. strength, MPa
	Cement, liters/m^3	Water content, liters/m^3		Sand, kg/m^3	Crushed stone, kg/m^3	Admixture Type F, liters/m^3	
		Total	Free				
Dolomite	400	180	160	725	1140	6.0	37.5 - 38.0
Pink lime stone	400	186	160	700	1060	6.0	34.0– 36.0

On the other hand, the two examined products of reinforcing steel are designated as 'Z' for a locally-manufactured one, and 'T' for an imported type that has been recently introduced to the local market. Tests include tension tests, cold-bend tests, and chemical analysis. The performances of examined steels were also investigated on site during fabrication of reinforcement in two large products currently under construction in Alexandria. Tests were performed at five various laboratories listed to table 4 whereas test results are described subsequently.

5. Results and discussions

In the proceeding section, results and discussions are divided in two phases; each phase presents one risky aspect at a time; coarse aggregate followed by reinforcing steel.

5.1. Aspect (i), coarse aggregates

Results of fundamental tests performed on coarse aggregates from different sources are listed in table 5. No significant differences were found between pink lime stones from different sources. Also, the two examined dolomites seem to be similar. However, some differences were noticeable between the two groups. The mean values for unit and specific weights of dolomites are 1.64 t/m^3 and 2.67, respectively as compared to 1.41 t/m^3 and 2.51 for pink lime stones. It is also evident that crushing values are relatively higher for pink lime stones as compared to dolomites. As expected concrete made with dolomites exhibited higher compressive strength than that where pink lime stones are incorporated providing similar cement contents and water-cement ratios.

On the other hand, another difference between the two types of aggregates; dolomite and pink lime stone, from sources 'B' and 'C' may be achieved through microscopic examination. Typical microscopic observations of the bulk interiors of the subject aggregates are shown in fig. 2 at 50x and 100x magnifications. Microstructures of both aggregates appear different. The grains of pink lime stone seems to be coarser than that of dolomite. This may explain the relatively low unit weight of aggregate 'C' (1.42 t/m^3) with respect to that of aggregate 'B' (1.63 t/m^3). In addition, aggregate 'C' appears more porous as compared to aggregate 'B'. It should be noted that these examinations were performed on cut-surfaces of aggregate's particle.

In fact, available results for all examined aggregates meet the requirements of the Egyptian code [1] with respect to grading, crushing value, percentage of materials finer than 80 µm, soundness, chlorides and sulfates contents. These findings imply that the examined types of crushed stones can be used as coarse aggregates in concrete. However the true story may be somewhat different.

Table 4
List of different laboratories where current experiments were performed

list	Laboratory	Tests
1	"Housing and Building National Research Center", Cairo	- X-ray diffraction analyses on aggregate. - Petrographic examination on aggregate. - Chemical analysis on aggregate.
2	"Production Eng. Center", Faculty of Eng., Alexandria University.	- Microscopic analysis on aggregates. - Chemical analysis on reinforcing steel.
3	"Testing material lab". Faculty of Eng., Alexandria University.	- Mechanical tests on reinforcing steel.
4	"Egyptian Copper Works", Alexandria.	- Mechanical tests on reinforcing steel. - Chemical analysis on reinforcing steel.
5	"Egyptian Testing Center", Alexandria.	- Concrete casting and testing. - Tests on aggregates.

Table 5
Results of fundamental tests performed on coarse aggregates from different sources

Source of coarse aggregate	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Type	Dolomite$^+$		Pink-lime stone^{++}					
NMS, in.	1.5"	3/4"	3/4"	3/4"	1.0"	3/4"	3/4"	3/4"
Crushing value, %	13.5	17.4	26.4	26.3	23.0	19.5	21.4	28.7
Fine materials (< 80 µm) , %	1.50	0.78	1.20	1.70	2.0	1.30	1.30	1.20
Chloride content CL^-, %	0.029	0.022	0.028	0.035	0.032	0.038	0.022	0.015
Sulfate content SO_3^{--}, %	0.305	0.281	0.360	0.320	0.380	0.300	0.360	0.170
Unit weight, t/m^3	1.65	1.63	1.42	1.40	1.37	1.43	1.41	1.40
Specific weight	2.69	2.66	2.50	2.52	2.51	2.48	2.51	2.50
Soundness, % of weight loss*	2.95	#	5.92	#	#	#	#	#

* Sodium sulfate was incorporated. (ASTM C88)
\+ From Suez area.
++ From Alexandria area.
\# Missing data

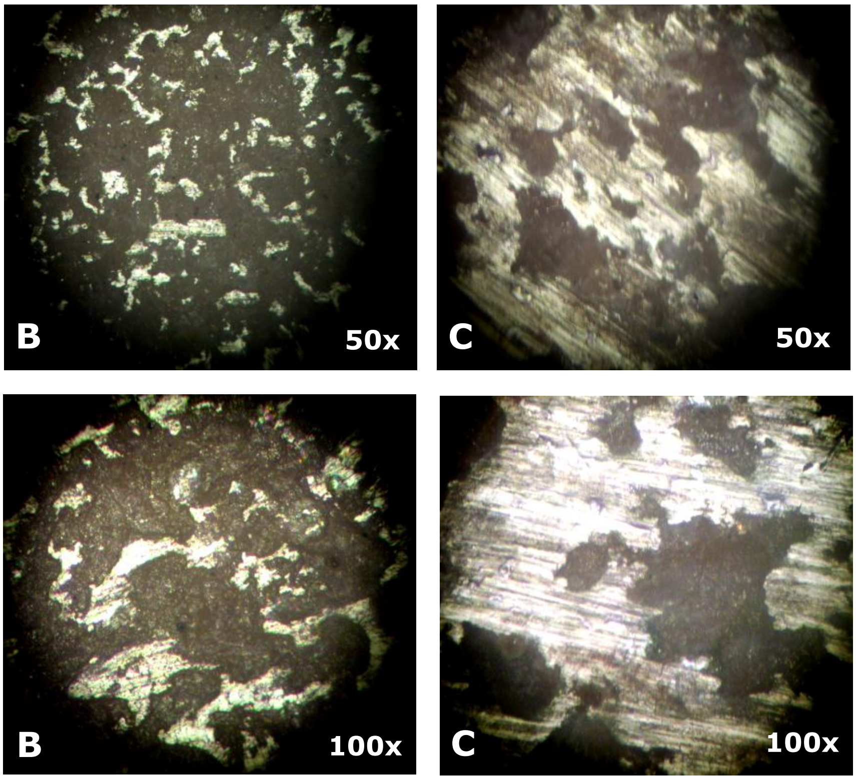
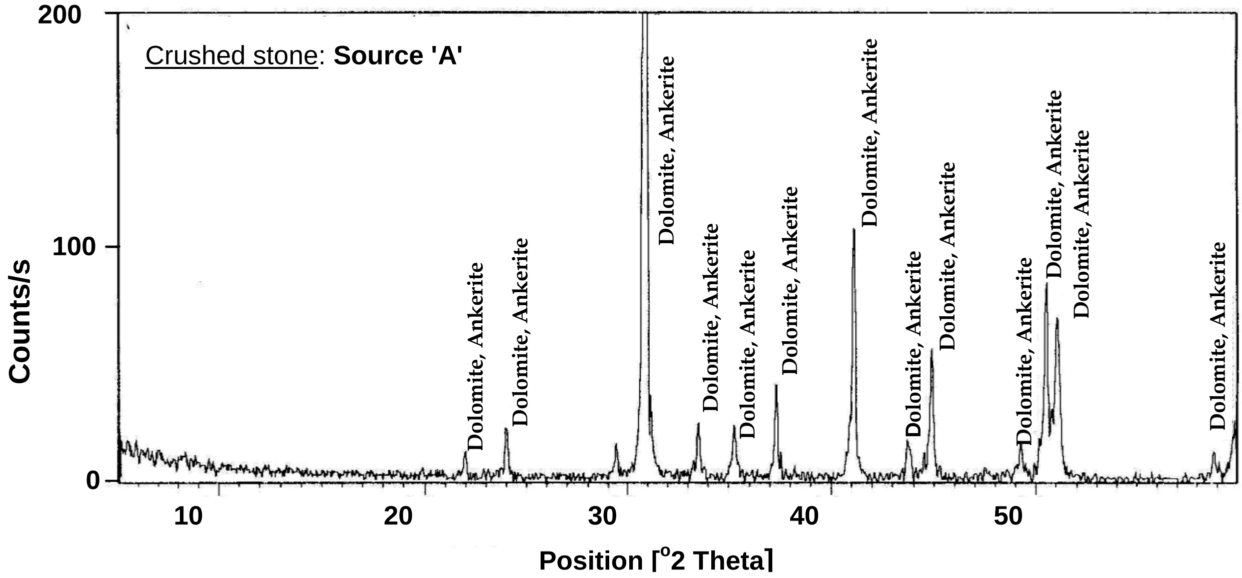


Fig. 2. Microscopic views of coarse aggregates; Dolomite 'B', and pink lime stone 'C'.

The X-ray diffraction patterns for samples representing the four selected types of carbonate aggregates ('A' to 'D') are shown in figs. 3, 5, 6 and 7. Some data are supported by petrographic analysis as shown in figs. 4. A comparison between the minerals in the four types of crushed stones is also shown in fig. 8. As seen, there is a noticeable difference in the compositions of examined aggregates.



Chemical Formula	Mineral	Quantity, %
CaMg $(CO_3)2$	Dolomite	81
Ca (Fe , Mg)$(CO_3)2$	Ankerite	18
Ca (CO_3)	Calcite	1

Fig. 3. X-ray diffraction analysis for crushed stone from source (A).

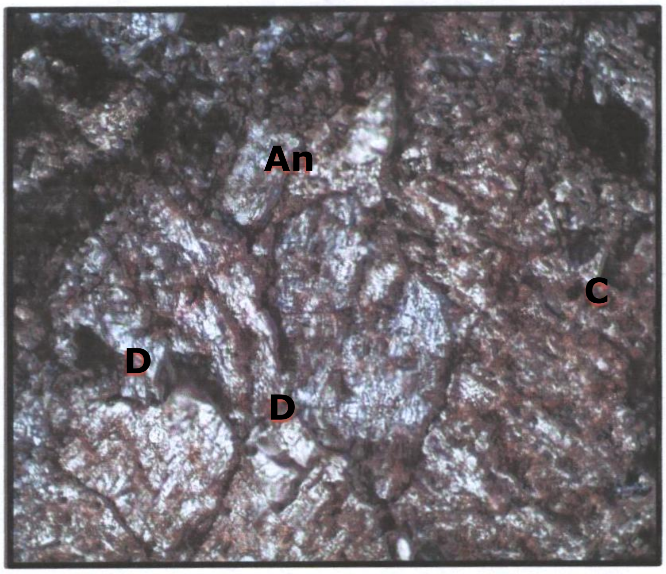
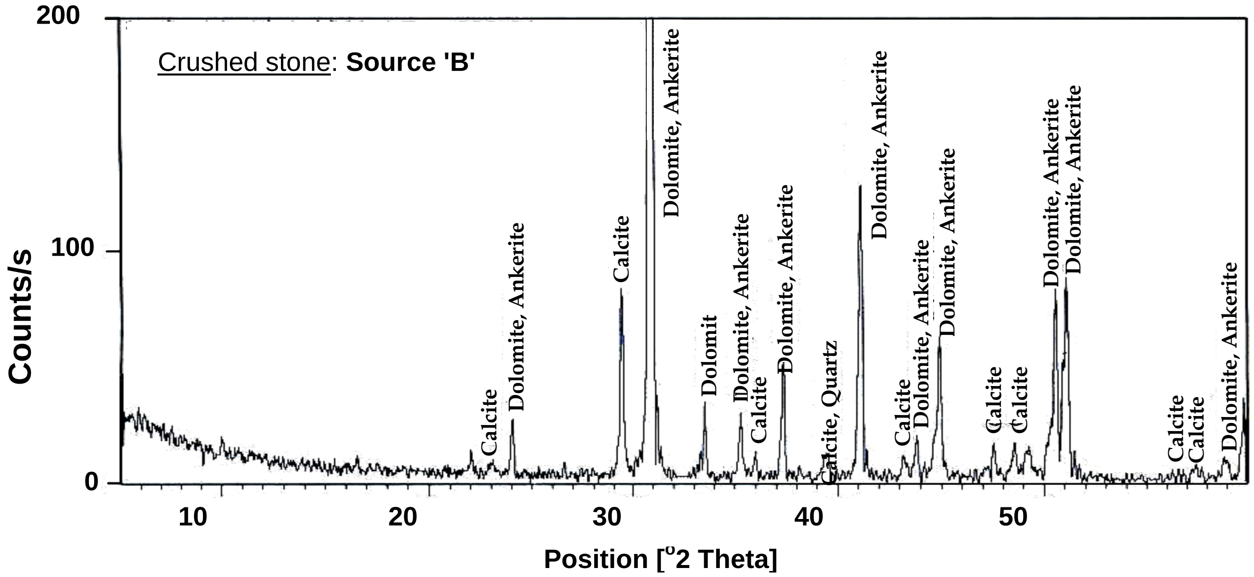


Fig. 4. Petrographic examination for crushed stone from source (A).



Chemical Formula	Mineral	Quantity, %
CaMg (CO$_3$)2	Dolomite	63
Ca (Fe , Mg)(CO$_3$)2	Ankerite	17
Ca (CO$_3$)	Calcite	6
SiO$_2$	Quartz	14

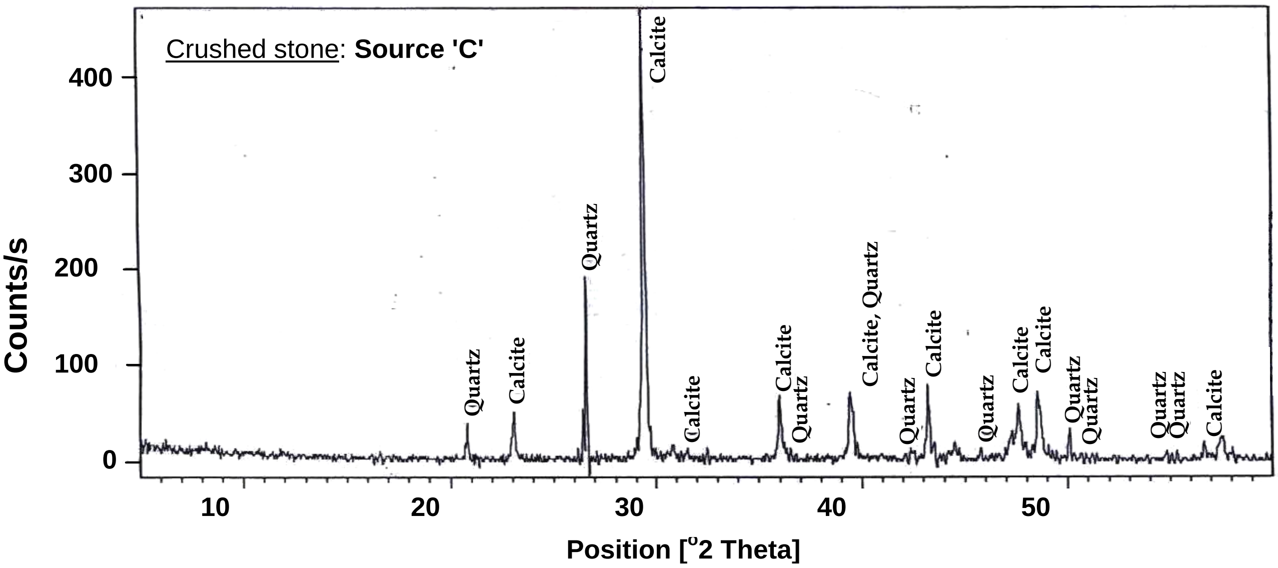
Fig. 5. X-ray diffraction analysis for crushed stone from source (B).

It is a fact that the main strategy employed by valid codes and standards, and acknowledges by consultants, and engineering communities, is to avoid the harmful expansion and cracking due to reactions of carbonate aggregates with concrete alkalinity. However, it appears that there is no simple and fast approach to identify and hence reject expansive crushed stones-aggregate from carbonate rocks.

Unfortunately, mortar bar expansion test (ASTM C 227) is not effective at judging the potential for expansion due to the alkali–carbonate reaction, while the rock cylinder expansion test (ASTM C 586) requires a one year-period and therefore is impractical, however it can be used in the detailed exploration of quarries or potential quarry sites, but can not be used for accepting aggregate stock in batch plants or construction sites. The only remaining tests for relatively quick assessment are the X-ray diffraction and petrographic examination in order to assure the absence of harmful compositions in crushed stone-aggregates with sharp attention to ankerite. These tests can be completed in a few days.

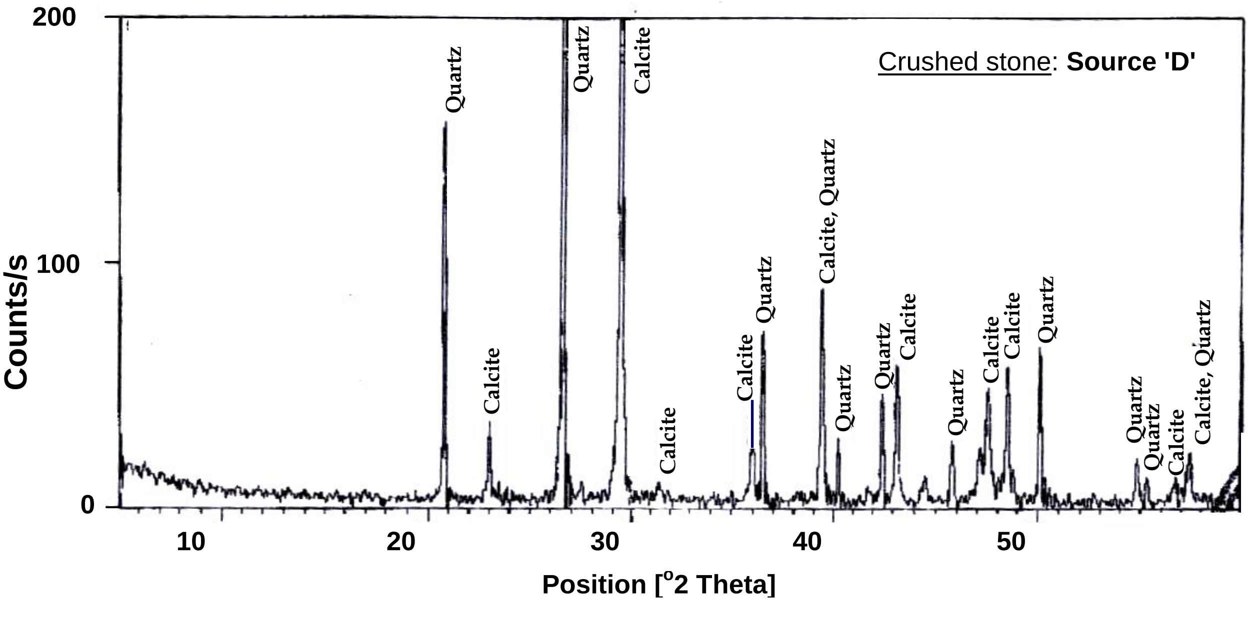
Results obtained in the current research indicate that crushed lime stones 'C' and 'D' consist of calcite and quartz. In contrast to this, it is evident from the X-ray diffraction analysis that the mineral 'ankerite', that is known to have expansive properties, do exist in both dolomites 'A' and 'B'. Up to 18% ankerite was recorded. Both types are mainly dolomites with lesser ankerite. Crushed stone 'A' consists of 81% dolomite and 18% ankerite while crushed stone 'B' contains 63% dolomite and 17% ankerite with some calcite and quartz as well. Petrographic examination of crushed stones from source 'A' confirms the presence of ankerite as shown in Fig. 4. It should be noted that the testing guide of the Egyptian Code [6] emphasizes that crushed lime stones that include ankerite should not be used as coarse aggregate in concrete.

Therefore, it is strongly believed that the use of these aggregates from sources 'A' and 'B' may result in critical sequences. As mentioned earlier, crushed stones from sources 'A' and 'B' are currently used for making concrete in batch plants. Pink lime stones tested here may not be susceptible to carbonate reaction with alkalinity that may be encountered in dolomites from Suez areas. However, this statement needs verification through comprehensive research program.



Chemical Formula	Mineral	Quantity, %
$Ca(CO_3)$	Calcite	68
SiO_2	Quartz	32

Fig. 6. X-ray diffraction analysis for crushed stone from source (C).



Chemical Formula	Mineral	Quantity, %
$Ca(CO_3)$	Calcite	38
SiO_2	Quartz	62

Fig. 7. X-ray diffraction analysis for crushed stone from source (D).

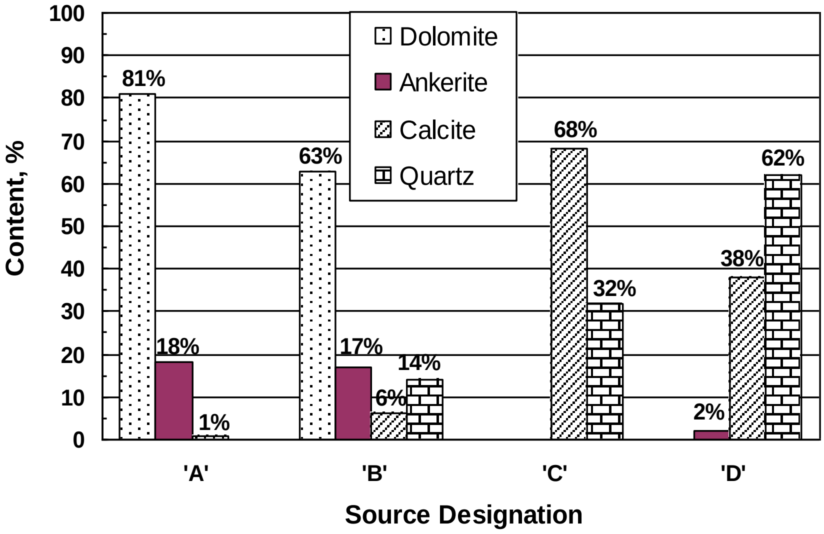


Fig. 8. Comparison of chemical components for crushed stone from different sources.

5.2. Aspect (ii); reinforcing steel

Results of the performed tensile tests on steel specimens from Products 'Z' and 'T' are summarized in tables 6 and 7 while their chemical analyses are listed in table 8. On the basis of the obtained results, it seems that all examined steel products from the two providers 'Z' and 'T' satisfy the requirements of the Egyptian code ECS 203 [1] for grade 400/600 and also pass the ductility assessment based on cold-bend tests as seen in fig. 9. Furthermore, chemical analysis of the steel meet the Egyptian Specification ESS 262 [21] that requires the percentages of carbon, sulfur, and phosphorus to be less than 0.045%, 0.06%, and 0.06%, respectively. However, other observed points may be of highly importance.

Mechanical properties of the locally manufactured steel 'Z' are very consistent. For the 14 tested specimens with various diameters, the yield stresses vary from 410 to 455 MPa with a mean value of 432 MPa and a coefficient of variation of 3.75%. Also, the ultimate stresses achieved range from 638 to 717 MPa with a mean value of 688 MPa and a coefficient of variation of 3.37%. In fact, the mean values for yield stresses for tested specimens representing lots (i) and (ii) are 435 MPa and 428 MPa, respectively. Also, the mean values for ultimate stresses are almost similar in both steel lots. In fact, the mechanical properties of steel 'Z' are very comparable. This finding indicates very good quality control during the manufacture of this steel product.

Contradictory, it is evident from table 7 that the results of the 12 tested specimens taken from the imported steel 'T' show high variations in mechanical properties from one lot to another. For instance, the ultimate stresses mean value varies from 652 MPa for Lot (iii) to 782 MPa for Lot (ii). Noticeable is also the fact that the yield stresses mean values for steel 'T' are 456 and 541 MPa for specimens taken from Lots (iii) and (ii), respectively. This inconsistency implies either poor quality control during the manufacture of steel 'T' or that the lots of imported steel 'T' are imported from different factories. Furthermore, the results of chemical analysis listed in Table 8 confirm the finding mentioned above. In fact, the locally manufactured steel 'Z' shows better quality control. Based on the above argument, it is strongly believed that when using the imported steel 'T' as reinforcement, tests should be performed on samples taken from every lot on site.

From another prospective, although most valid codes do not explicitly request for an upper value for yield stress in reinforcing steel, the high recorded yield stresses for steel product 'T' may not be very accepted in seismic design and may also lead to over-reinforced sections. In addition, it is generally accepted that higher yield stress values provide usually lower ductility and vise versa [22].

Table 6
Mechanical properties of reinforcing steel from Provider 'Z'

Steel Lot	Sample No.	Nominal diameter, mm	Effective diameter Φ, mm	Weight, kg/m	Yield		Ultimate		%age of elongation	Cold-bend test
					load, kN	Stress, MPa	load, kN	Stress, MPa		
(i)	Z1*	16*	15.95	1.568	89.8	450	142.3	713	15.6	accepted
	Z2		15.96	1.570	87.8	439	143.3	717	16.9	,,
	Z3	18	18.03	2.004	111.8	438	180.5	707	15.6	,,
	Z4		18.03	2.004	112.8	442	181.0	709	16.7	,,
	Z5*	22*	21.99	2.982	171.9	452	261.9	690	15.9	,,
	Z6*		22.17	3.032	160.9	417	246.2	638	18.2	,,
	Z7		22.06	3.002	160.9	421	260.0	680	18.2	,,
	Z8		22.04	2.995	160.9	422	246.7	647	14.1	,,
	Average yield and ultimate stresses				435 MPa		688 MPa		-	
	Coefs. of variation for stresses V, %				3.1%		4.4%		-	
(ii)	Z9	10	10.08	0.626	36.3	455	54.0	676	17.0	accepted
	Z10		10.02	0.631	34.8	442	54.9	697	19.0	,,
	Z11	12	12.10	0.904	47.1	410	79.5	691	17.5	,,
	Z12		12.14	0.908	51.0	440	78.5	677	18.3	,,
	Z13	16	15.86	1.550	81.4	412	137.3	695	15.0	,,
	Z14		15.82	1.544	80.9	410	137.3	695	16.3	,,
	Average yield and ultimate stresses				428 MPa		689 MPa		-	
	Coefs. of variation for stresses V, %				4.6%		1.4%		-	
All	Over-all coefficient of variation V, %				3.75%		3.37%		-	

* Adverse signs were noticeable while being bent on site.

Table 7
Mechanical properties of reinforcing steel from Provider 'T'

Steel Lot	Sample No.	Nominal diameter, mm	Effective diameter Φ, mm	Weight, kg/m	Yield		Ultimate		%age of elongation	Cold-bend test
					load, kN	Stresses, MPa	load, kN	Stress, MPa		
(i)	T1	10	10.00	0.621	37.3	475	53.0	675	18.0	accepted
	T2	12	11.97	0.884	56.7	504	76.8	683	20.0	,,
	T3		12.13	0.907	58.1	502	79.4	687	19.0	,,
	T4		12.10	0.902	56.9	495	77.5	674	19.0	,,
	T5	16	16.00	1.578	109.9	547	135.4	674	13.8	,,
	T6		16.05	1.588	111.8	553	136.8	677	13.1	,,
	Average yield and ultimate stresses				513 MPa		678 MPa		-	
	Coefs. of variation for stresses V, %				6.0%		0.8%		-	
(ii)	T7*	10*	9.70	0.621	39.4	533	57.9	783	15.0	accepted
	T8	12	11.50	0.888	56.6	545	80.9	779	14.0	,,
	T9	16	15.60	1.600	104.4	546	149.6	783	14.0	,,
	Average yield and ultimate stresses				541 MPa		782 MPa		-	
	Coefs. of variation for stresses V, %				1.3%		0.3%		-	
(iii)	T10	16	15.95	1.569	91.2	457	130.5	653	16.3	accepted
	T11		15.95	1.569	88.8	445	129.0	646	16.9	,,
	T12		15.98	1.575	93.2	465	131.9	658	14.4	,,
	Average yield and ultimate stresses				456 MPa		652 MPa		-	
	Coefs. of variation for stresses V, %				2.2%		0.9%		-	
All	Over-all coefficient of variation V, %				7.7%		7.5%		-	

* Adverse signs were noticeable while being bent on site.

Table 8
Chemical properties of examined reinforcing steel

Provider	Sample No.	Description	Diameter Φ, mm	Carbon, %, 'C'	Sulfur, %, 'S'	Manganese, %, 'Mn'	Phosphor, %, 'P'	Silicon, %, 'Si'
'Z'	Z5*	Taken from cracked bar far away from crack	22*	0.1594	0.0278	1.015	0.0301	0.1588
	Z6*	Taken from cracked bar very close to crack	22*	0.1362	0.0264	1.011	0.0410	0.1509
	Z7	Taken from unused bar	22	0.1601	0.0368	1.029	0.0452	0.2256
'T'	T5	Taken from unused bar	16	0.3800	0.0230	0.6800	0.0300	0.3300
	T7*	Taken from unused bar	10*	0.2280	0.0326	0.5570	0.0433	0.1667
	T10	Taken from cracked stirrup	16	0.3529	0.0451	0.8030	0.0180	0.1928

* Adverse signs were noticeable while being bent on site.

Fig. 9. The acceptance of steel bars based on the results of cold-bend tests.

It is generally agreed that the ductility of steel for concrete reinforcement is its ability to achieve significant deformations without marked increase of stresses beyond the yield strength of steel [17]. Actually, sharp bends will have weakened the steel at the corner, right where it needs most strength [19]. To ponder on the question whether a cold-bend test is reliable for ductility assessment of reinforcing steel further inspections of reinforcement were conducted on sites.

In one project, the product steel 'Z' was used for reinforcing pile caps where 16, 18, and 22 mm-bars were employed, while in another project, the product steel 'T' was utilized for fabricating the reinforcement of columns. For bending steel product 'Z', the electric bender shown in fig. 10 was used, while bending steel bars 'T' in a relevant project was done using manually powered benders. During fabrication, the process was completed when the designated angle of bend had been reached; mostly is 90°. Since most operators uses only one former for all sizes of reinforcing steel, it was ensured in the current investigation on site that the bending process conformed to the requirements for minimum bend diameters according to 'Guide for testing - ECS 203' [6] and 'ASTM A615M' [18] as mentioned earlier in tables 1 and 2. The mandrel diameter was almost 4-5 times the diameter of the bar being bent.

Up to this point all steel products seem to meet valid standards and codes [1, 18, and 21]. However, a somewhat different trend was noticeable on site where the subject steel products had been used as reinforcements. Unfortunately, despite being accepted based on the results of cold-bend test, most bars from products 'Z' and 'T' showed undesirable signs during fabrication on site. In fact, the bars cracked and sometimes are broken during the bending process to 90° on site. Cracks were visible to the unaided eye. The situation was more pronounced for the 22 mm-bars from product 'Z' and the 10 mm-bars from product 'T'. It should be pointed out that after the fracture occurrence of steel bars, the situations on the two subject sites were given attentions and the convex surfaces of the bend regions of reinforcing steel were examined for cracks or surface irregularity. Under these circumstances, the work in the two projects postponed and additional tests were required by the consultants.

Again, all repeated tested samples were accepted based on cold-bend tests and satisfied the requirements of steel grade 400/600. In fact, it was amazing to see the ability of the bar specimens to resist bending in the lab up to 180° while they cracked on site when bent only up to 90°. It should be noted that the three specimens 'T7', 'Z5', and 'Z6' were taken from bars that had been severely cracked on site as it is evident from the photographs shown in figs. 11 to 13. Actually, the ability of the subject steel products to withstand the cold-bend test up to 180° while being cracked or broken on site when bent to a lesser degrees is somewhat eccentric. There are no good simple answers; however, this finding may be explained from other views.

Fig. 10. Bending machine for steel bars during construction.

Traditionally, most laboratories follow the guided-bend test shown schematically in fig. 1-c for performing cold bend test on steel bars due to its simplicity, while the bending process on site follow a different arrangement as shown in fig. 10. This difference between the two setups may be responsible to a large extent on the distinction between steel performances under lab and site conditions where most studied bars showed brittle behaviors. According to ASTM E0290 [20], different results may be obtained with the use of different bend arrangements given in fig. 1 for bend tests. On the other hand, the result may be greatly affected by the rate of motion in forming a bend. In most cases, the bending rate on site is always faster than that in the lab where a hydraulic machine is utilized. In fact, the speed of bending must conform to that of the anticipated process application of the material being tested [20].

It is strongly believed that the semi-guided-bend test setup illustrated in fig. 1-b seems more reliable than the guided-bend test setup given in fig. 1-c. Mostly, the latter may not represent the site and hence may lead to unreliable results. Accordingly, it may be reasonable to state that it is the responsibility of the consultant to select the appropriate bend test that represents the fabrication process on site. Selected test can hence be conducted as an acceptance criterion. In fact, the use of a rotating device in laboratory to apply the bending force is recommended. Also, reduce diameter for pins or mandrel than required by the code is suggested for performing cold-bend test in the lab. This reduction will give a more reliable assessment for ductility of reinforcement steel. Actually, it very reasonable to require that the diameter of pins or mandrel used in the lab for a specific diameter of bar to be less than that used on site by a value equal to bar diameter. For instance, if the diameter of bar being bent on site is 16 mm, a mandrel's diameter on site may be equal to 4d whereas the pin diameter to be used in performing bend test is equal to 3d, where d is the bar diameter.

Fig. 11. Global views of steel stock from provider 'Z' on site.

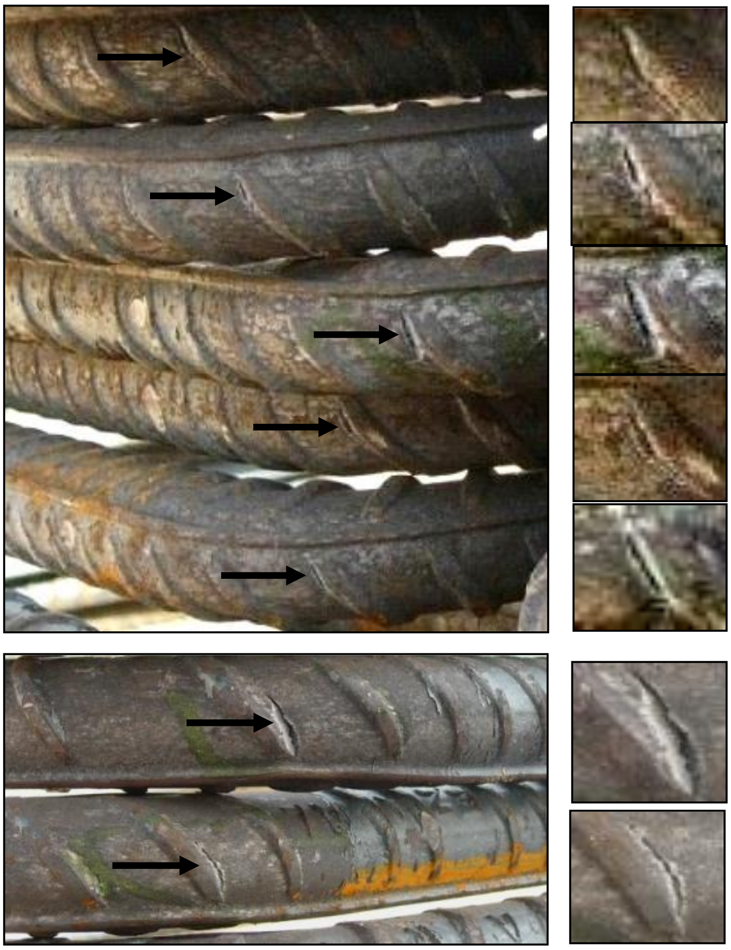


Fig. 12. Cracks appeared in most of the 22 mm- steel bars from provider 'Z' on site.

Fig. 13. Serious cracks and fracture of steel bars with different diameters on site [provider 'Z'].

Fig. 14. Cracks and fracture of steel bars during bending on site [provider 'T'].

The consequences of the unintentional use of invisibly-cracked reinforcement at the bend corners may simply result in insufficient development length in reinforced concrete elements under certain situations and certainly lead to unsafe sections. It is therefore advisable in practice that the convex surfaces of selected bent bars are examined for cracks or other open defects regardless the results of cold bend test.

5.3. Closure

Although the two risky aspects discussed in this paper seem to be unrelated to each other, they may ultimately lead to one end. Utilizing reactive crushed stones may cause premature concrete deterioration, whereas the use of unnoticeable cracked reinforcement may lead to unsafe concrete sections. Both aspects certainly have severe consequences. Actually, it is of highly importance to properly recognize reactive aggregates as well as cracked reinforcement prior to construction, since there is no way of preventing the consequences after placing concrete. The screening findings described herein may hence be of highly importance in the area of concrete construction. More studies on the prescribed viewpoints; crushed stones and reinforcing steel, are recommended, from which practical criteria can be established and may hence be introduced in codes provisions.

6. Conclusions

The main conclusions obtained from this study under the described battery of tests may be divided into two scopes:

6.1. Scope (1); Coarse aggregates

1. Samples of crushed stones from eight different sources are examined, of which two are quarried from Suez area while the remaining six types are provided from different quarries in Alexandria area. Results of fundamental tests indicate that all examined types of coarse aggregates meet the requirements of the Egyptian Code and hence can be used for making concrete.
2. The X-ray diffraction may effectively be used to assure the absence of ankerite in the dolomite or lime stone aggregates. In fact, mortar bar expansion tests (ASTM C 227) is not designated for judging expansion due to the alkali-carbonate reaction while the rock cylinder expansion test (ASTM C 586) requires a one year-period and hence is not a practical tool for accepting aggregate stock.
3. Concrete high specified strength can be obtained using deliberate and reactive crushed stones, as well. Actually, concrete compressive strength is mainly affected by cement content and water-cement ratio. Satisfying the concrete grade on site is not enough to ensure well performance.
4. Microscopic examination of the bulk interiors of dolomite and pink lime stone at 50x and 100x magnifications indicates differences in microstructures of both aggregates. Pink lime stone seems to be coarser than dolomite.
5. The X-ray diffraction patterns for samples representing four selected types of carbonate aggregates indicate the presence of ankerite in the two examined dolomites that are currently used for making concrete in some batch plants. Up to 18% ankerite is recorded. Since

ankerite is known to have expansive properties, premature concrete deterioration may be occurred.

6. Petrographic examination for crushed stone from one source confirms the presence of ankerite. It should be noted that the testing guide of the Egyptian Code [6] emphasizes that crushed lime stones that include ankerite should not be used as coarse aggregate in concrete.

7. Results indicate that crushed lime stones produced from Alexandria area consist mainly of calcite and quartz, whereas the crushed stones produced from Suez area are mainly dolomites with lesser ankerite. Crushed stone 'A' consists of 81% dolomite and 18% ankerite while crushed stone 'B' contains 63% dolomite and 17% ankerite with some calcite and quartz as well.

8. As a precautionary measure, it is strongly recommended to use X-ray diffraction supported by petrographic examination on crushed stones from carbonate rocks to discover the presence of ankerite. These tests can be completed in a few days.

9. At the mean time, it is strongly recommended that official in charge departments start comprehensive regional investigations on carbonate rocks in different quarries aggregates in different areas in Egypt because the reactive rock is not identified by usual tests. Actually, it is of highly importance to properly recognize potentially reactive aggregates prior to construction, since there is no way of preventing the reaction after placing concrete.

6.2. Scope (2); Reinforcing steel

1. Samples of reinforcing steel from two providers were examined in the lab and inspected on site during fabrication. The first product 'Z' is locally manufactured while the second one 'T' is imported. Results indicate that the two types of steel products meet the requirements of the Egyptian Code [1] for steel grade 400/600 based on the results of tension tests, cold bend tests, and chemical analysis, as well.

2. The locally manufactured steel 'Z' shows better quality control. Results indicate that mechanical properties of steel 'Z' are very consistent whereas the imported steel 'T' shows high variations in mechanical properties from one lot to another. It may be therefore advisable that when using the imported steel 'T' as reinforcement, tests should be performed on samples taken from every lot on site.

3. For ductility assessment, most relevant codes and standards depends to a large extent on performing cold bend test on steel bars following different test setups. Three arrangements may be followed; semi-guided-bend test (Arrangements 'A' and 'C') where rotation devices are used and guided-bend test using hydraulic testing machine. As noted by ASTM E0290 [20], the results obtained by different arrangements for bend tests may be different. Also the bending speed may greatly affect the results.

4. Despite being accepted based on the results of cold-bend test (guided-bend test), most bars from products 'Z' and 'T' cracked and sometimes broke through during the bending process to fabricate reinforcement on sites during the construction of two large projects in Alexandria. Cracks were visible to the unaided eye. In fact, it was surprising to see the bar specimens able to resist bending in the lab up to 180^o while they crack on site when bent only up to 90^o providing that the requirements for minimum bend diameters according to relevant codes are fulfilled.

5. The obtained results combined with field observations imply that the guided-bend test that is traditionally used in most laboratories has a tendency to pass all steel products from ductility point of acceptance. This setup may not represent the site and hence may lead to unreliable results.

6. The result of cold bend test may be greatly affected by the rate of motion in forming a bend. In most cases, the bending speed on site is always faster than that in the lab where a hydraulic machine is utilized for performing bend test. It is therefore advisable that the speed of bending in the lab must be comparable to that of the anticipated process application.

7. It may be concluded that the semi-guided-bend test setup using rotation device illustrated in Fig. 1b seems more reliable and simulating field conditions. Mostly, the latter

may not represent the site and hence may lead to unreliable results. Accordingly, it can be stated that it is the responsibility of the consultant to select the appropriate bend test that represents the fabrication process on site. Selected test can hence be conducted as an acceptance criterion.

8. The consequences of the unintentional use of invisibly-cracked reinforcement at the bend corners may result in insufficient development length in reinforced concrete elements under certain situations and lead to unsafe concrete sections.
9. In practice, it is recommended that the convex surfaces of selected bent bars are examined for cracks or other imperfections regardless the results of cold bend test.

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