Result Validation Analysis of Steel Testing Machines

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***Abstract*—**Structural failures occur due to a number of reasons. These may include under design, poor workmanship, substandard materials, misleading laboratory tests and lots more. Reinforcing steel bar is an important construction material, hence its properties must be accurately known before being utilized in construction. Understanding this property involves carrying out mechanical tests prior to design and during construction to ascertain correlation using steel testing machine which is usually not readily available due to the location of project. This study was conducted to determine the reliability of reinforcing steel testing machines. Reconnaissance survey was conducted to identify laboratories where yield and ultimate tensile strengths tests can be carried out. Six laboratories were identified within Ibadan and environs. However, only four were functional at the time of the study. Three steel samples were tested for yield and tensile strengths, using a steel testing machine, at each of the four laboratories (LM, LO, LP and LS). The yield and tensile strength results obtained from the laboratories were compared with the manufacturer's specification using a reliability analysis programme. Structured questionnaire was administered to the operators in each laboratory to consider their impact on the test results. The average value of manufacturers' tensile strength and yield strength are 673.7 N/mm^2 and 559.7 N/mm^2 respectively. The tensile strength obtained from the four laboratories LM, LO, LP and LS are given as 579.4, 652.7, 646.0 and 649.9 N/mm^2 respectively while their yield strengths respectively are 453.3, 597.0, 550.7 and 564.7 N/mm^2. Minimum tensile to yield strength ratio is 1.08 for BS 4449: 2005 and 1.15 for ASTM A615. Tensile to yield strength ratio from the four laboratories are 1.28, 1.09, 1.17 and 1.15 for LM, LO, LP and LS respectively. The tensile to yield strength ratio shows that the result obtained from all the laboratories meet the code requirements used for the test. The result of the reliability test shows varying level of reliability between the manufacturers' specification and the result obtained from the laboratories. Three of the laboratories; LO, LS and LP have high value of reliability with the manufacturer i.e. 0.798, 0.866 and 0.712 respectively. The fourth laboratory, LM has a reliability value of 0.100. Steel test should be carried out in a laboratory using the same code in which the structural design was carried out. More emphasis should be laid on the importance of code provisions.

***Keywords*—**Reinforcing steel bars, reliability analysis, tensile strength, universal testing machine, yield strength.

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I. Introduction

BUILDINGS, like all other structures, are designed to support certain intended loads without deforming excessively. The aim of the building design is to meet its owner's requirements functionally and to satisfy safety requirements. No part of such building should pose a hazard to its occupants [4]. However, there have been previous newspaper reports (such as that of Synagogue Church of All Nations building collapse around Ikotun Egbe area of Lagos state on 12 September, 2014,) of building collapses and structural failure at a time or the other due to a number of reasons.

Structural failures can be attributed to factors ranging from poor workmanship, inadequate design, use of substandard materials, corruption, government policies etc. Reference [7] attributed building failure to the following; design faults (50%), faults on construction site (40%) and product failure (10%). Reference [3] on the other hand categorized the following as major causes of structural failures: environmental changes, natural and man-made hazards; improper presentation and interpretation in the design output. These failures can be partial or total in nature.

The two principal materials used in reinforced concrete structures are concrete and reinforcing steel bars to complement each other in areas of compressive and tensile strengths [6]. During structural design, it is normally assumed that the materials (concrete and steel) will attain a certain strength which is used to carry out the desk design from which construction drawings are prepared. It is therefore necessary that concrete and steel reinforcement bars undergo compressive and tensile strength tests to determine their standard strength which must conform with the initial assumed design strength.

The compressive and tensile strengths are important mechanical properties of these major materials (concrete and steel reinforcement) that make up reinforced concrete structures [9]. Tests are however carried out to ascertain these properties after an assumption has been made during the desk design. The accuracy of both the compressive and steel tensile strength tests depends greatly on the reliability of the machine used for test. Since the result obtained from the testing machine will be adopted in the structural design, hence such machine must be reliable to a very large extent. The value of the characteristic strength which is of utmost importance for structural design can only be obtained using steel testing machine. If the machine to be used for the test is faulty, the result will be non-reliable and tells a lot on the result of the design and definitely on the construction and vice versa. In order to have safer and economic structure, a reliable laboratory result showing the characteristic property of the material to be used is of utmost importance.

Steel reinforcement is categorized as primary and secondary reinforcement. The steel reinforcement which is needed to resist the design load as a whole is known as primary reinforcement [10]; secondary reinforcement on the other hand is used to enhance durability and aesthetics by limiting the cracks and stresses that may be caused due to harsh conditions [8].

Reinforcing steel bar is an important construction material, hence its properties must be accurately known before being utilized in construction processes. Mechanical testing requirements for reinforcement bar can vary, but typically fall into the following basic test categories: Tensile, Bend, Compression, and Fatigue.

The tensile properties of the material include its resistance pull and stretch. The extent of its elongation before reaching breaking point and the required force to cause this break are very important [11]. For most materials, the initial resistances to force, or modulus, and the point of permanent deformation, are obtained from plots of force against elongation. Analysis of force elongation or stress-strain curves can convey much about the material being tested, and it can help in predicting its behavior.

The Ultimate Tensile Strength (UTS) is usually found by performing a tensile test and recording the stress against the strain. The UTS is correspondent to the peak point of stress-strain curve. Its value is independent of the size (diameter) of the steel bar. However, it depends on factors like defects, temperature and so on [12].

Various standards exist to help ensure that reinforcing bars produced throughout the world conform to the same physical, chemical, and mechanical properties regardless of their source. Proper mechanical testing is then necessary to ensure conformity. International standards, such as, American Society of Testing and Materials (ASTM), British Standards (BS) and other industrial standard organizations have standard test methods.

In this study, a steel sample with known manufacturer's specification was subjected to tensile strength at selected laboratories and reliability analysis was carried out on the tensile results obtained to ascertain the integrity of the testing machines.

Reliability can be explained to be the measure of agreement and consistency of an observation [5]. The degree of the reliability is a function of the relation between the test results. If there is an agreement between these results, the reliability is high and implies that the result is consistent and reliable.

II. Materials and Method

A. Survey and Questionnaire

A survey of the available steel reinforcements and laboratories within and outside the city of Ibadan was carried out. Six laboratories were selected at random but only four were functional during execution of this study. The steel used has manufacturer's strength specification i.e. steel certificate.

A structured questionnaire was developed to get information on the operator, testing machine and the standard/ code from each of the selected laboratories. The first part of the questionnaire focused on evaluating the technical knowhow of the operator. Under this part, questions such as level of education, years of experience, registration with professional body, and code or standard being used were asked. The second part of the questionnaire lays emphasis on the steel testing machine. Questions such as machine type, frequency of calibration, maintenance practices, repair etc. were asked. The questionnaire was filled by the operators of all the selected laboratories.

B. Samples Collection

The sample of 16 mm diameter reinforcing steel bar used for this study was bought from a marketer in Ibadan. The sample was cut into varying length based on specification of the laboratory. Three specimens were tested in each laboratory.

C. Testing Laboratories

The four laboratories of which include; Oyo State Ministry of Works, Secretariat, Ibadan (Materials Testing Laboratory), The Polytechnic Ibadan (Mechanical Engineering Department), Segun Labiran & Associates, and Materials Science Department of Obafemi Awolowo University, are represented respectively as LO, LP, LS and LM. The first letter in the abbreviation denotes Laboratory while the second letter denotes first letter of the name of the laboratory. Table I shows the laboratories and the standard used.

TABLE I
LIST OF LABORATORIES AND STANDARD USED

Name	Abbreviation	Standard
Oyo State Ministry of Works	LO	BS 4449
The Polytechnic Ibadan	LP	BS 4449
Segun Labiran & Associates	LS	BS 4449
Material Science Department, Obafemi Awolowo University (OAU)	LM	ASTM A615

D. Samples Preparation

All the specimens used were free from physical defect. The specimens were gently cut as required by various laboratories. For instance, LM required that the specimen be machined as shown in Fig. 1. LO makes use of 500 mm length of the sample for the steel tensile and yield test. Hence three specimens of 16 mm diameter, 500 mm length of high yield reinforcement bar were used. On the other hand LP and LS required 600 mm length for the same number of specimens and diameter. The tests were carried out in accordance to codes used by the laboratories.

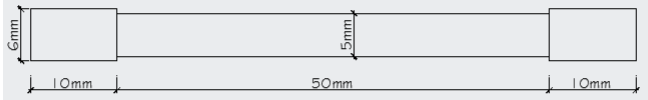

Fig. 1 Machined specimen for LM

E. Specimen Testing

Reinforcing steel bar could be subjected to a number of physical/mechanical and chemical tests. Physical/mechanical tests on steel include Tensile, Impact, Fatigue, Bend, Torsion etc. The mechanical tests carried out in this research are tensile strength test, yield strength test and percentage elongation of each of the steel reinforcements. Yield strength is of utmost importance in this research as this value is being used while carrying out reinforced concrete design for different structures.

F. Testing Equipment

Universal Testing Machines (UTM) were used for the tests at the four laboratories. The machines work on the principle of stress – strain relationship and it starts from the point when the material is being loaded and the load is gradually increased. This increased loading brings about elongation of the steel till it reaches its yield point. Further increment in loading of the steel specimen leads to its failure. The point at which the steel breaks is known as the breaking point i.e. UTS of the steel.

G. Diameter Check

Diameter check was carried out on the steel samples using micrometer screw gauge to confirm the diameter of the steel. This is necessary as the area of the sample will be computed to get the yield and tensile strength of the steel sample.

H. Test Procedure

There is a slight difference in the test procedure based on the laboratories. Three out of the four laboratories use the same type of steel testing machine (UTM, Analogy) and adopt BS 4449 for testing. The other laboratory uses UTM, Digital and adopt [1] for the test. The major difference is the specification of specimen required. For the laboratory using digital UTM, the specimen undergoes a machining process. This is done to fit the specimen firmly into the testing machine.

I. Reliability Analysis

After obtaining the results from the four laboratories in which the tests were carried out, the average value for yield and tensile strengths were calculated for each laboratory and for manufacturers' specification. The average values were then subjected to analysis using Inter Rater Reliability Method. The reliability values for the manufacturer were compared with the laboratories and each laboratory with other laboratories. It involves checking the degree of agreement among raters i.e. level of homogeneity.

III. Results and Discussion

The administered questionnaires help to know dependability of the results from each laboratory. The personal data of the operators of the steel testing machines obtained include gender, level of education, years of experience, registration with professional body (COREN) etc. The results obtained from the analysis are shown in Table II.

TABLE II
BASIC INFORMATION OF LABORATORY OPERATORS

Name	Education level	Years of experience	Registration with COREN	Frequency of Maintenance
LO	PGD	10	No	Always
LP	HND	10	Yes	Always
LS	M. Sc.	5	Yes	Rarely
LM	M. Sc.	11	Yes	Always

The 16 mm diameter as reported by manufacturer was measured and confirmed with a micrometer screw gauge. Certainty in diameter of the steel sample has great influence on the accuracy of the tensile and yield strength. Both tensile and yield strengths are functions of the cross sectional area.

The manufacturer's specification (MS) for yield and tensile strengths are presented in Table III while Table IV shows the ratio of UTS to yield strength. This ratio is compared with the code provision.

TABLE III
MANUFACTURERS' YIELD AND TENSILE STRENGTHS

Sample	**Yield Strength (N/mm^2)**	**Tensile Strength (N/mm^2)**	**Tensile/Yield Ratio**
1	545	689	1.26
2	537	634	1.18
3	597	698	1.17
Average	559.7	673.7	1.20

TABLE IV
ULTIMATE TO YIELD STRENGTH RATIO

Name of Laboratory	**Avg. Tensile Strength (N/mm^2)**	**Avg. Yield Strength (N/mm^2)**	**Avg. Tensile/Yield Ratio**		**Code**
			Specimens	**Code Provision**	
LM	579.4	453.33	1.28	≥ 1.15	ASTM A615
LO	652.7	597.0	1.09	≥ 1.08	BS 4449
LP	646.0	550.7	1.17	≥ 1.08	BS 4449
LS	649.9	564.7	1.15	≥ 1.08	BS 4449

Reliability Analysis

The results of the reliability analysis for yield and tensile strengths are presented in Tables V and VI respectively. The yield and tensile strengths were also checked for level of homogeneity with one another and with the manufacturers' specification. This was done using ANOVA.

TABLE V
RELIABILITY TEST FOR YIELD STRENGTH

	Manufacturers' Specification	**LM**	**LO**	**LS**	**LP**
Manufacturers' Specification	1	0.100	0.798	0.610	0.712
LM	0.100	1	0.189	0.409	0.267
LO	0.798	0.189	1	0.866	0.652
LS	0.866	0.390	0.769	1	0.769
LP	0.712	0.267	0.652	0.769	1

IV. Discussion of Results

The responses from the questionnaire administered show that the operators' level of education is adequate for a better understanding of steel testing machines. The minimum years of experience of the respondent with machine are three years while the maximum is above 10 years. With this range of years of experience, it is expected that they are familiar with the working principles of the machine. Similarly, a good number of the attendants were COREN certified. However, the operator not yet certified displayed a good understanding of the concept of steel testing. All the laboratories performed the test in conformity with recognized standards; also, the machines were regularly maintained.

The manufacturer's yield and tensile strengths as presented are in line with the code provision for the steel used for this test. The steel used for the test is a B500B steel grade [12]. According to Table 10 of [12], the minimum and maximum values of yield are given as 485 N/mm^2 and 650 N/mm^2. This shows that the MS value for yield strength is in line with the code provision. The average value of the yield from MS is 559.7 N/mm^2 while the value for tensile is 673.7 N/mm^2. The yield and tensile strengths were further checked for tensile/yield strength ratio and compared with the code provision. The manufacturer's tensile to yield strength ratio is presented in Table III. Reference [2] and BS 4449 specify a minimum tensile/yield strength ratio of 1.15 and 1.08 respectively. It could be clearly observed that the value of tensile/yield ratio specified by the manufacturer is above code provision i.e. 1.20 > 1.08 or 1.15.

Reliability

The reliability analysis is presented in Tables V and VI for yield and tensile tests respectively. The values were compared with the manufacturer's data and also compared among the laboratories. While comparing the result from each laboratory and the specification of the manufacturer, there is a 100% reliability as evident in the 1.0 value reliability shown in Tables V and VI. The result of the reliability test shows varying level of reliability between the manufacturers' specification and the result obtained from the laboratories. The values of reliability test show that three laboratories have high values of reliability with the manufacturers' i.e. 0.798, 0.866 and 0.712 for LO, LS and LP respectively. The fourth laboratory, LM has a reliability value of 0.100. This pattern is also repeated in the reliability test for tensile strength with the three laboratories above having a high value of reliability with the manufacturers' specification, the values are 0.992, 0.617 and 0.542 respectively. The fourth laboratory LM has a reliability value equal to 0.373.

TABLE VI
RELIABILITY TEST FOR TENSILE STRENGTH

	Manufacturers' Specification	LM	LO	LS	LP
Manufacturers' Specification	1.000	0.373	0.992	0.617	0.542
LM	0.373	1.000	0.479	0.422	0.405
LO	0.992	0.479	1.000	0.500	0.569
LS	0.617	0.422	0.500	1.000	0.997
LP	0.542	0.405	0.569	0.997	1.000

Some of the factors that could be responsible for this variation include varying size of test sample and machining process. In one of the laboratories considered, machining process was carried out on the steel. This is done in line with ASTM standard to help the steel specimen fit perfectly into the testing machine. Lots of heat is generated in the course of the machining process and this could be responsible for the low value of yield and tensile results observed. The other three laboratories carried out the steel test in line with BS 4449 standard. In this standard, there is no provision for machining process. The samples are tested directly in their original form.

In construction, the steel are used in their original form without any form of machining. Machining process involves altering the steel in its original form as the steel sample will be machined into specified dimension.

V. Conclusion

Knowing the actual property of reinforcing steel used in reinforce concrete structure is of utmost importance. Yield and tensile strengths are one of these properties. It is through steel test that the value of yield and tensile strengths of steel can be obtained. In line with the results, the steel test should be carried out in a laboratory using the same code to that of structural design strength parameters.

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