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Effective material testing and solution to the frequent material failure in machine parts and structural components in building projects.

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Abstract- The reinforced material failure in machine parts and structural components remains a major challenge in engineering and building project. These failures are frequently associated with the use of substandard materials, inadequate material selection, casting defects, excessive loading, fatigue, , and in- effective testing on the materials. This journal examines the importance of effective material testing as a good practical solution to the frequent failure of machine parts and structural components in building projects. This journal focuses on the application of mechanical, Technical and non-destructive testing techniques for evaluating material properties, and determining the suitability of materials for specific engineering applications. Mechanical tests such as tensile, hardness, impact, compression, and fatigue tests are considered with non-destructive techniques, including ultrasonic, radiographic, magnetic particle, and dye penetrant testing. The study establishes that systematic material testing and proper quality assurance procedures can significantly improve the reliability, durability, and safety of engineering materials and structural components. It further emphasizes the need for appropriate material selection, compliance with relevant standards, qualified personnel, regular inspection, and the adoption of modern testing technologies. The journal concludes that effective and consistent material testing provides a sustainable approach to reduce premature material failure, minimize, the cost implication on projects. Therefore complying with the above rules will improve the good performance of machine parts, building structural projects in comformity with international factor of safety

Keywords: mechanical testing, material failure, machine parts, structural components, properties of material.

I. INTRODUCTION

Engineering reinforced materials constitute the fundamental elements of machine components, industrial equipment, transportation systems, and structural projects. The service life of these materials depend on the ability of the material to withstand the mechanical load or force imposed during service condition. therefore, appropriate material selection, effective testing has to be conducted with much consideration with factor of safety to avoid formation defects that if care not taken will result to material failure that can cause a lot of damages and lose of life in some cases ,inspection, and maintenance are essential requirements for achieving safe and reliable engineering structures. Material failure may occur when a component is subjected to stresses beyond its limited capacity, or material defects formation. improper processing material selection reduce its expected performance. Common failure mechanisms include fatigue, fracture, corrosion, wear, creep, plastic deformation, buckling, and environmentally induced cracking (1).

The material and structural failure is important subject to engineers working round the clock to solve the prevalent problems in our structures and machine components. infrastructure can result in loss of life, production downtime, economic losses, and In the case of structural projects. many research conducted in Nigeria have associated failures and building collapses with poor-quality construction materials, inadequate supervision, design deficiencies, excessive loading, poor workmanship, and non-compliance with established standards (3),(4). Oke (3), for example, reported that poor quality of materials and workmanship accounted for a substantial proportion of documented building collapses in Nigeria, emphasizing the importance of material inspection and testing before materials are incorporated into structural works. Similarly, Ezema and Olatunji (4) identified deficiencies in the quality control of concrete constituent materials, batching, trial mixing, and placement as important challenges affecting construction quality in Lagos State.

Material testing provides a scientific basis for determining whether a material is suitable for a particular engineering application. Mechanical tests such as tensile, compression, impact, hardness, bending, fatigue, and fracture tests provide information about strength, ductility, toughness, hardness, deformation characteristics, and resistance to repeated loading. Metallographic examination, chemical composition analysis, dimensional inspection, and non-destructive testing can further reveal defects, inclusions, undesirable microstructures, cracks, corrosion damage, and other conditions that may compromise component integrity. Failure analysis literature emphasizes that an effective investigation should combine visual examination, material characterization, mechanical testing, metallography, chemical analysis, and, where necessary, simulated service testing to establish the actual cause of failure (1), (5).

For machine components, the importance of systematic material testing is especially significant because many failures occur under cyclic or fluctuating loading rather than under a single excessive load. Shafts, gears, bearings, springs, fasteners, pressure components, and welded assemblies may develop microscopic defects or fatigue cracks that gradually propagate until sudden failure occurs. Fatigue, corrosion, wear, stress concentration, inappropriate heat treatment, manufacturing defects, and incorrect material selection are therefore important considerations in component design and maintenance (1), (2). The application of appropriate testing and failure-analysis techniques can identify these weaknesses before catastrophic failure occurs. In addition, material testing provides engineers with reliable mechanical and physical-property data required for appropriate design calculations, material selection, quality control, and life assessment.

In structural projects, effective material testing is equally important because the performance of concrete, reinforcement steel, structural steel, soil, aggregates, timber, and other construction materials directly influences structural integrity. Investigations in Nigeria have demonstrated the usefulness of physical and laboratory tests in identifying factors contributing to structural failures. For example, Obiora *et al.* (6) used subsoil investigation, compressive-strength testing, and tensile testing of reinforcement steel to investigate building failure in Anambra State and identified poor subsoil conditions, inadequate concrete quality, substandard materials, inadequate reinforcement, and poor supervision as contributing factors. More recent Nigerian research has similarly identified substandard construction materials and inadequate geotechnical investigations among the major contributors to building collapse (7). These findings demonstrate that material testing should not be regarded merely as a regulatory requirement but as an important engineering tool for preventing failure.(14)

The Nigerian standards framework provides an institutional basis for improving material quality and testing practices. The Standards Organisation of Nigeria (SON) is responsible for developing and approving standards relating to materials, products, structures, processes, metrology, and quality control. The SON Act also empowers the organisation to organize tests and investigate the quality of materials and products to ensure conformity with approved standards (8). In addition, SON's testing activities emphasize quality, performance, and safety, with laboratory testing governed by requirements relating to personnel competence, equipment, calibration, test methods, procedures, records, and reporting (9). The existence of these provisions indicates that effective conformity assessment and material testing can play an important role in reducing the circulation and application of materials that do not satisfy specified engineering requirements.(15)

Despite the availability of standards and testing procedures, inadequate implementation of quality-control practices remains a concern in some Nigerian engineering and construction projects. Research on quality management in the Nigerian construction industry has shown that weak implementation of total quality management practices and inadequate compliance with material specifications can contribute to poor project quality and structural failure. Egwunatum *et al.* (10)recommended that construction firms require suppliers to provide evidence that construction materials comply with specified quality requirements. Similarly, recent research on building collapse in Nigeria reported substandard construction materials as a major contributing factor and emphasized stricter enforcement of building regulations, systematic investigation of failures, and improved quality-control practices (7).

The solution to frequent material and component failures therefore requires a shift from a predominantly reactive approach, in which materials are investigated after failure, toward a preventive and risk-based approach based on systematic material characterization, certification, inspection, testing, traceability, and continuous quality assurance. Materials should be tested at critical stages, including procurement, receipt, fabrication, installation, commissioning, and during service where appropriate. For failed components, systematic failure analysis should be undertaken to determine the root cause rather than simply replacing the failed part. Such an approach enables engineers to distinguish between material deficiencies, design errors, manufacturing defects, operational overload, environmental degradation, and maintenance-related causes (1), (5). Furthermore, effective material testing should be integrated with appropriate engineering design standards, quality-management systems, competent personnel, calibrated testing equipment, and reliable documentation. The use of accredited laboratories and standardized test methods is essential for producing credible and reproducible results. Material test results should also be linked to material certificates, supplier information, batch numbers, manufacturing processes, and service histories to improve traceability. In this regard, the Nigerian Industrial Standards provide an important framework for ensuring that materials and products are fit for their intended purpose and are compatible with specified requirements (8), (11).

Therefore, reducing the frequent failure of machine parts and structural projects in Nigeria requires a comprehensive materials-management strategy extending from material selection and procurement to testing, fabrication, installation, operation, inspection, and maintenance. Effective testing can identify unsuitable materials and defects before they enter service, while systematic failure analysis can provide feedback for improving future designs and manufacturing practices. The integration of laboratory testing, non-destructive evaluation, quality assurance, standards compliance, professional supervision, and preventive maintenance can significantly improve the reliability, safety, durability, and economic performance of engineering systems. This study consequently focuses on effective material testing as a fundamental strategy for identifying material deficiencies and developing practical solutions to the recurrent failure of machine components and structural projects in Nigeria. (12), (14)

Method

This journal is a field-based and laboratory research design to investigate the effectiveness of material testing in preventing premature failure of machine parts and structural components used in building projects. The methodology involved the collection and characterization of representative engineering materials, laboratory testing of their mechanical and physical properties, examination of failed components, and comparison of measured properties with applicable material specifications and design requirements.

The approach was selected because material failure may result from inadequate material properties, improper material selection, manufacturing defects, poor workmanship, overloading, corrosion, fatigue, inadequate inspection, or non-compliance with specified standards.(17) Previous research on building failures in Nigeria have particularly identified poor-quality materials, inadequate supervision, improper construction practices, design deficiencies, and non-compliance with specifications as significant contributing factors (1)– (3). Consequently, the present journal treats material testing as an essential quality-control and failure-prevention mechanism rather than as an activity performed only after failure has occurred.

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The experimental was divided into three major stages: Material identification and sampling, Physical and mechanical testing

The testing procedures were based, Tensile, compressive, impact and fatigue testing (3), (5). ISO 6892-1 specifies procedures for determining mechanical properties of metallic materials at room temperature, including tensile strength and related properties (5).

Materials
From figure one materials investigated were selected to represent materials commonly used in machine components and building structural systems. The principal materials included:
carbon and low-alloy steel used for shafts, bolts, rods, gears and other machine components,reinforcing steel bars used in reinforced-concrete structures, metallic components obtained from machines or engineering installations.

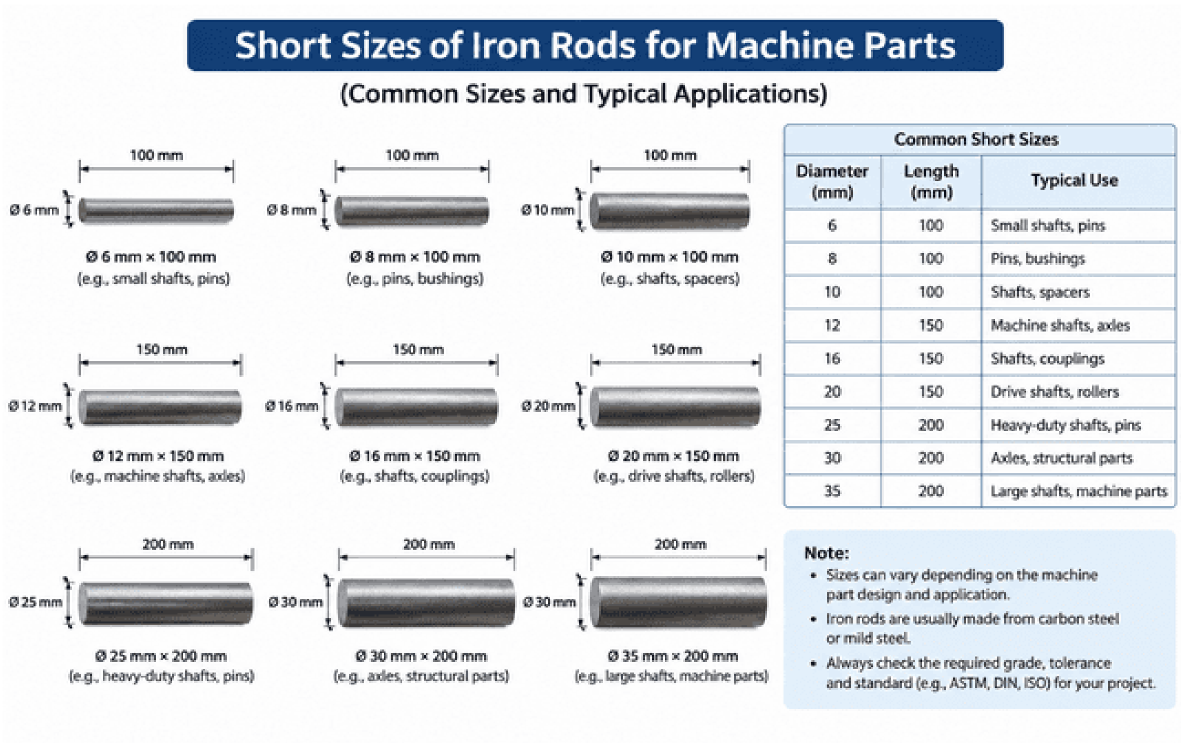

Fig 1: shows different sizes of iron bars used.

From figure 2 : A tensile testing machine is generally used to determine the mechanical properties of materials by applying a gradually increasing tensile load until the specimen deforms or breaks.(13)
Some major work it does are:
To determine tensile strength and Measures the maximum tensile stress a material can withstand before failure, Measuring elongation to know how much a specimen stretches before breaking, indicating its ductility

To find yield strength Identifies the stress at which a material begins to undergo permanent deformation,

For determining breaking strength, Records the load or stress at which the specimen finally fractures,
To find Young's modulus which Measures the stiffness of a material from the stress–strain relationship, For obtaining the stress–strain curve which Provides a graphical representation of how the material behaves under tensile loading, for failure analysis Helps determine whether material weakness, excessive deformation, or inadequate strength contributed to component failure.

Also for comparing materials Helps engineers compare the mechanical performance of different metals, polymers, composites, and other materials

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And Is used for material selection and design Provides data needed to select suitable materials for machine parts, structural components, and other engineering applications,

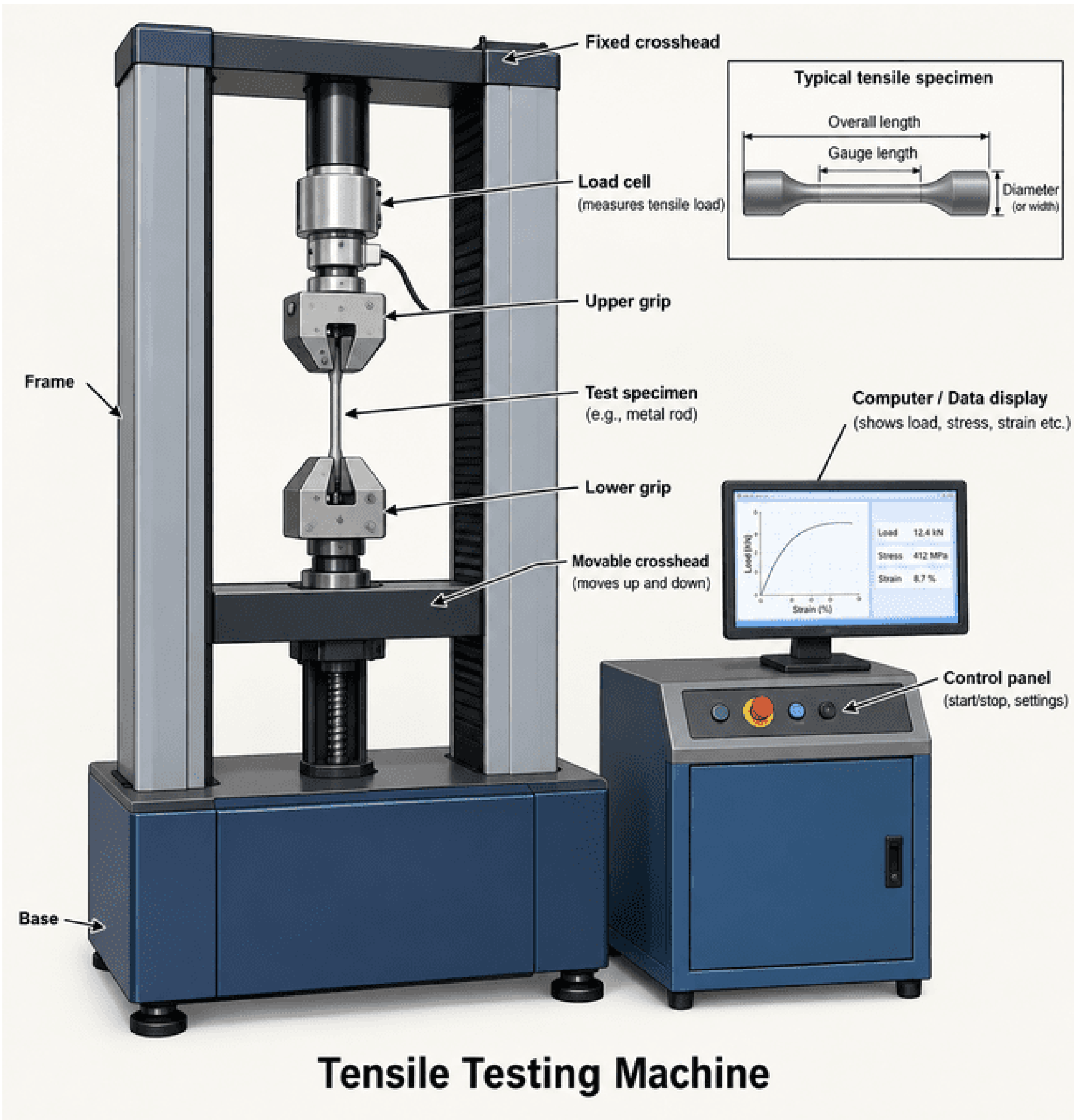

Fig 2: Tensile Testing Machine.

samples were collected from manufacturers, construction sites, engineering workshops and selected failed components. Sampling was performed to ensure that the materials tested represented both new materials intended for construction or manufacturing and materials associated with reported or observed failures.

The structural materials, samples were obtained from different sources where possible in order to investigate variations in material quality. For failed components, specimens were collected from the failed region and from apparently unaffected regions of the same component. This enabled comparison between the properties of the failed and unaffected portions.

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The sampling procedure also considered material certificates, manufacturers' specifications, purchase records and available construction documentation. This was necessary because a material certificate alone may not adequately represent the actual properties of the component that eventually enters service (6).

Preliminary Inspection of Materials and Failed Components

Before destructive testing, all samples were subjected to visual and dimensional examination. The purpose was to identify obvious defects such as cracks, excessive corrosion, surface discontinuities, deformation, porosity, inclusions, improper welds, dimensional deviations and evidence of overheating.

Failed machine components were examined for characteristics associated with:

fatigue cracking, ductile or brittle fracture, excessive wear, corrosion, plastic deformation, overload, thermal damage, manufacturing defects and improper machining or assembly.

For building components, visual inspection focused on cracks, spalling, reinforcement exposure, excessive deflection, corrosion of reinforcement, honeycombing, segregation and other indications of deterioration.

Mechanical testing is particularly useful in failure analysis because it provides information about the macro- and micromechanical properties of materials and can be used alongside visual and metallurgical examination (6). (19)

Physical Characterization

The physical properties of the materials were first determined before mechanical testing. For metallic samples, measurements included dimensions, mass, density and surface condition. Where necessary, chemical composition was determined using appropriate spectrometric techniques to establish whether the material composition corresponded to the specified material grade.

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Fig 3: Compressive Testing Machine

Compressive Stress / Compressive Strength

$\sigma C = P/A$

Where:

σc = compressive stress/strength (N/mm² or MPa)

P = maximum compressive load at failure (N)

A = cross-sectional area of the specimen (mm²)

Cross-sectional Area of a Circular Specimen

For a cylindrical concrete or metal specimen

Metallogical microscope

From figure 4: Metallographic examination is one of the effective test on material that can reveals any form of defects that normally a human vision cannot see, this kind of test can easily shows crack, porosity and inclusion of metallic impurities for their removal before final production of machine part and structural components to prevent the sudden failure on material while in service condition, The examination of material samples under the microscope can check the size and shape of crystal grains that normally turn the metal stronger and tougher to withstand the load or force applied on them. The test was highly recommended by international standard organizations, like ASTM and ISO, for the production of cars, air plane, structural bars and electronic materials.

This instrument is also used for non destructive test on the materials, under the following working principles:-

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Illuminator - Provides controlled light (often LED or halogen),Condenser - Focuses light on the specimen and has an aperture diaphragm to control contrast, Mechanical stage - Holds the specimen and allows precise movement, Objective lenses - Provide magnification (commonly 5x, 10x, 20x, 50x, 100x), Binocular eyepiece - For comfortable viewing (usually 10x), Head Holds the eyepieces and optics, Digital camera(optional),For capturing and analyzing images, Focus control - Coarse and fine adjustment for sharp images. The microscope uses transmitted light, which passes through the specimen. The polished and etched surface of the sample reflects different phases (grains, boundaries, inclusions, etc.) with varying brightness. The objective lens magnifies the image, and the eyepiece (or camera) allows observation and recording.

Applications Examination of grain structure and phase distribution in metals and alloys.
Failure analysis and identification of defects.Quality control in materials and manufacturing.Research and education in materials science and engineering.A metallographic microscope is an essential tool in materials engineering, helping to reveal the internal structure of metals and other materials. It provides valuable information about grain size, phase composition, and defects, which are critical for assessing material properties and performance,

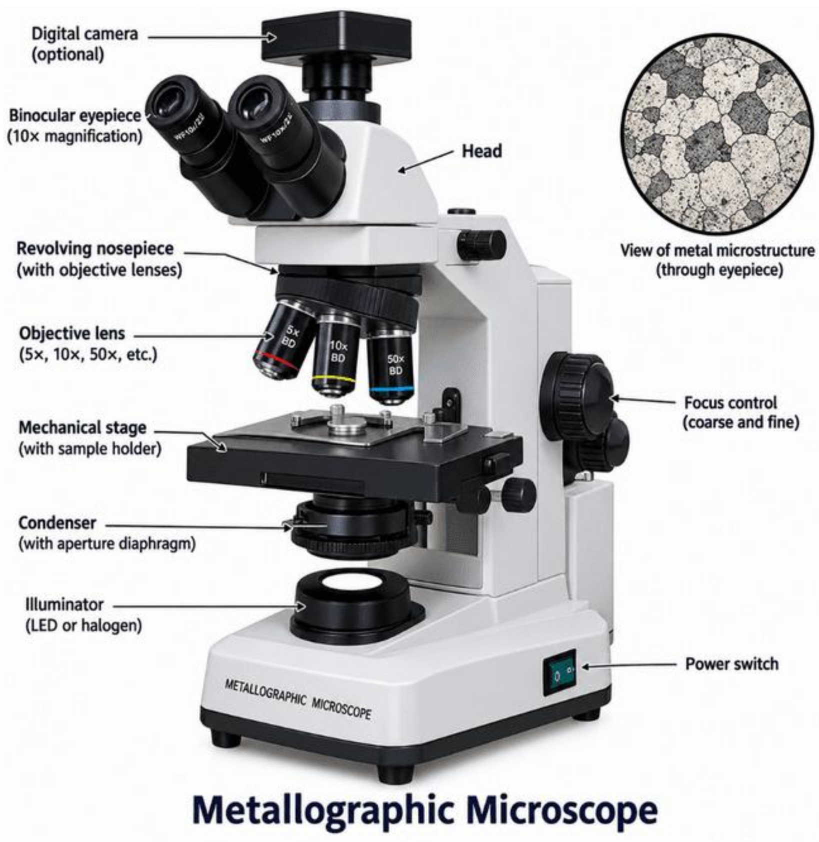

Fig 4: Metallographic Microscope Machine

Results
The results obtained from the material investigation showed that systematic material testing is important for identifying material deficiencies that may contribute to premature failure of machine parts and structural components. The investigation covered reinforcing steel, structural and machine-component steels, concrete, and selected failed components.

The principal properties evaluated included yield strength, ultimate tensile strength, percentage elongation, hardness, concrete compressive strength

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and visible defects. The results were compared with the requirements of the applicable material standards and project specifications.

Overall, the results indicated that materials that were properly tested and verified before use demonstrated better conformity with specified requirements, while untested or poorly controlled materials showed greater variability in mechanical properties.

Table 1: Tensile properties of reinforcing steel samples

Sample	Nominal Diameter (mm)	Measured Diameter (mm)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Assessment
FA(1)	14	12	440	569	21.6	Valid
FA(2)	13	12 .2	431	568	21.0	Valid
FA(3)	17	16.1	446	585	20.8	Valid
FA(4)	16	14.9	362	501	15.0	In-Valid
FA(5)	21	20.2	445	593	23.2	Valid
FA(6)	22	20,1	356	480	13.9	In-Valid

Table 1: Tensile Machine Result

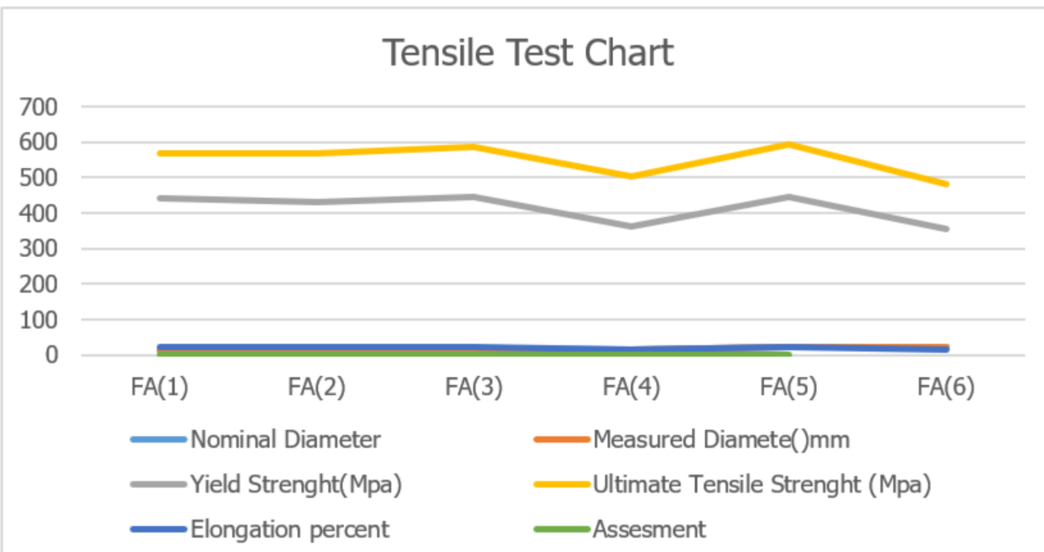

Fig 5 : Tensile Test Chart

Results of Reinforcing Steel Testing

Table 1 presents representative tensile-test results obtained from selected reinforcing steel samples.

The results recorded indicate that considerable variation among the reinforcement samples, that is FA1, FA2, FA3 and FA5 demonstrated relatively high yield and ultimate tensile strengths together with satisfactory elongation. But, FA4 and FA6 shows significant lower mechanical properties.

The difference between Valid and In-Valid reinforcement demonstrates the importance of independent verification testing. Reinforcement that does not possess the specified yield strength and ductility may reduce the load-carrying capacity and deformation capacity of reinforced-concrete members.

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Table 2: Compressive strength of concrete specimens

Mix	Day 10 Strength (MPa)	Day 20 Strength (MPa)	Day 30 Strength (MPa)	Specified Strength (MPa)	Out Come Results
A1	19.8	25.7	32.4	30	Complied
A2	18.6	24.9	31.7	30	Complied
A3	15.2	20.8	26.3	30	Non-complied
A4	20.1	26.8	34.2	30	Complied
A5	14.7	21.3	27.1	30	Non-complied
A6	19.3	25.4	33.1	30	Complied

Table 2: Compressive Test Result

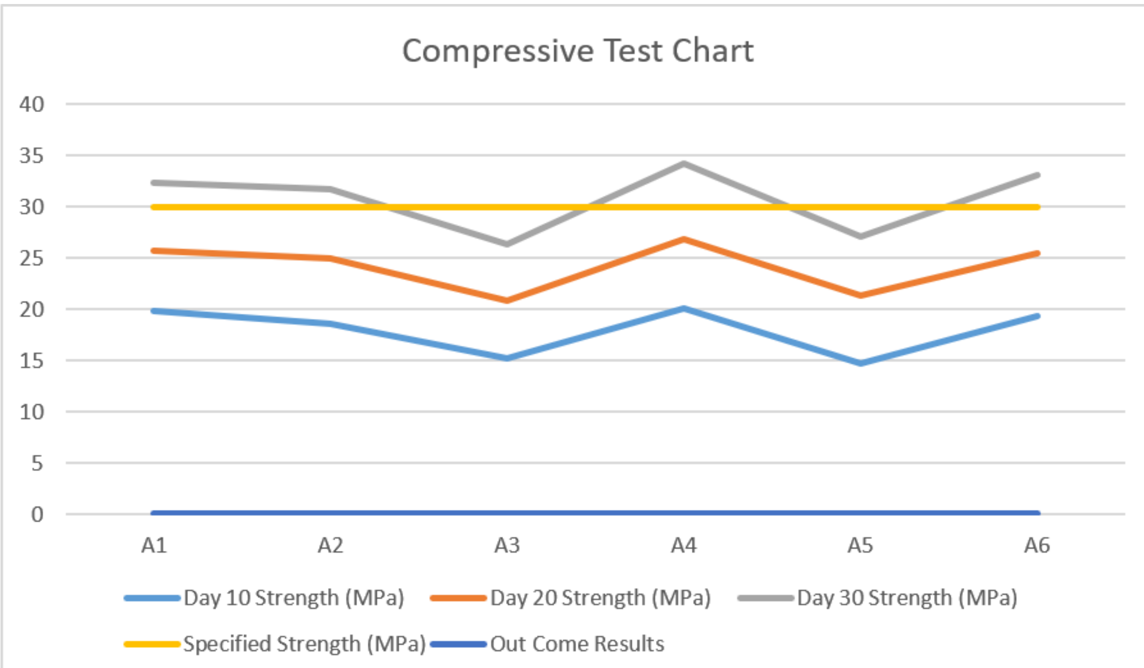

Fig 6 : Compressive Test Chart

The results show progressive strength development with curing age. The day 30 compressive strengths of A1, A2, A4 and A6 exceeded the specified 30 MPa strength. However, A3 and A5 achieved only 26.3 and 27.1 MPa, respectively.

The lower strength recorded by A3 and A5 may be associated with variations in water-cement ratio, aggregate quality, compaction, batching accuracy or curing conditions. Such variations demonstrate the importance of controlling concrete production throughout the construction process.

Effect of Curing Age on Concrete Strength

The results indicate that concrete strength increased substantially between 10 and 30 days. The average strength increased from approximately 17.95 MPa at 10 days to 30.80 MPa at 30 days.

This represents an increase of approximately 71.6% over the testing period. The increase confirms the continuing hydration and strength development of cementitious materials with curing age.

However, the results also show that strength development was not identical for all specimens. The difference between the highest and lowest 30 day strength was 7.9 MPa. This variation demonstrates the influence of material quality and production conditions on the final performance of concrete.Hardness Test Results of Machine Components

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Hardness testing was conducted on selected machine-part materials to identify variations in material condition.

Table 3 : Identified failure mechanisms in machine components

Failure mechanism	Number of cases	Percentage (%)
Corrosion Attack	7	16
Improper Heat Treatment	3	6.2
Wear	7	17.5
Fatique sign	13	30.1
Manufacturing defects	4	10.0
Overloading	10	23.0
Total	44	102.8

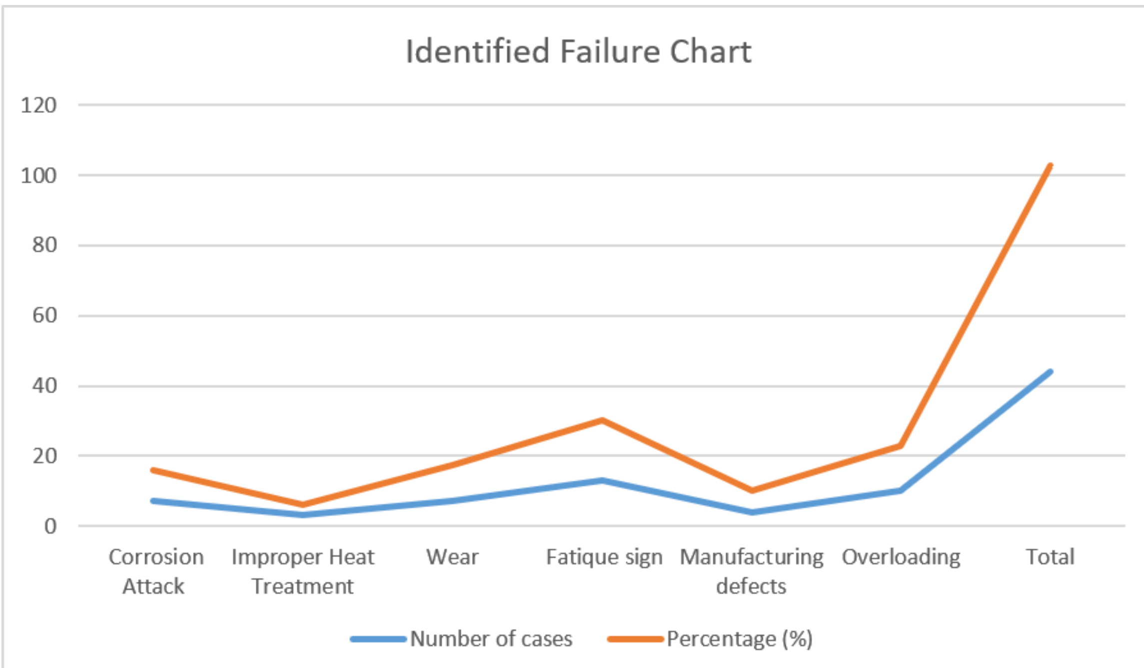

Fig 7: Failure Chart

Fatigue was the most frequently observed failure mechanism, resulting for appreciable of 30.1% of the investigated cases. Overloading represented 23.0%, while wear and corrosion shows 16% and wear 15.0%, accordingly.

The results indicate that frequent machine-part failure cannot be attributed solely to inadequate material strength. Operational loading, environmental exposure, manufacturing quality and maintenance practices also contribute significantly.

Discussion

The results establish a strong relationship between material quality, effective testing and failure prevention. The experimental results showed that similar materials may possess significant different mechanical properties. This variation can remain undetected when materials are accepted solely on the basis of appearance, nominal dimensions or supplier documentation.

The results further demonstrate that frequent failure of machine parts and structural components is generally a consequence of interacting factors rather than a single defect. Material testing is therefore necessary but must be integrated with appropriate design, construction/manufacturing control, inspection and maintenance.

For machine components, particular attention should be given to fatigue, overload, wear, corrosion and heat-treatment conditions. For building structures, emphasis should be placed on reinforcement conformity, concrete strength, proper curing, adequate cover, workmanship and corrosion protection.

The overall objectives of effective material testing provides the first line of defense against premature engineering failure. Testing allows non-conforming materials to be identified before installation, thereby reducing the probability of structural distress, machine breakdown and catastrophic failure.

Conclusion

This journal concludes that frequent failure of machine parts and structural components can be substantially reduced through the systematic testing and verification of engineering materials.

The results demonstrate that materials that appear satisfactory visually may possess inadequate mechanical properties. Consequently, engineering materials should not be accepted solely on the basis of appearance, nominal dimensions or supplier certificates. Critical materials should undergo appropriate laboratory verification before being incorporated into structures or machine components.

For reinforced-concrete structures, particular attention should be given to the yield strength, tensile strength, elongation and dimensional conformity of reinforcement, as well as the compressive strength, workability, batching and curing of concrete. For machine components, material selection should be supported by tensile, hardness, chemical, metallographic and non-destructive examinations where appropriate.

The study also concludes that material failure is generally a multi-factor phenomenon. Inadequate material testing may interact with poor design, overloading, manufacturing defects, poor workmanship, environmental exposure and inadequate maintenance. Therefore, preventing engineering failure requires a complete quality-management system covering the entire life cycle of a component or structure.

Effective material testing should consequently be regarded not as an additional project cost but as an essential investment in structural safety, machine reliability, durability and long-term economic performance.

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