

COMPARING THE EUROPEAN STANDARDS AND THE AMERICAN STANDARDS FOR TESTING CONCRETE MECHANICAL PROPERTIES



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Dedicated to Prof. György L. Balázs for his 65th birthday

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Europe and the United States have a worldwide significance in the field of concrete control and construction, as well as the cleared and specified standards, according to many countries adopted their standards and regulations in the field of concrete quality control and assurance as proof of the Europe and US strong standards and due to lack of their regulations. This research compares the European standards, the American Society for Testing and Materials (ASTM) and American Concrete Institute (ACI) standards for testing the mechanical properties of concrete. The research focuses on compressive strength, flexural tensile strength, shear strength, and modulus of elasticity as key properties for assessing the quality and performance of concrete. The study found variations in the specimen size, preparation, and curing requirements, as well as testing procedures and acceptance criteria among the European, ASTM and ACI standards. The research also compared the specimen preparation and curing standards among the different standards. The research highlights the importance of following the appropriate standards and testing procedures to ensure the test results' reliability and accuracy. Proper specimen preparation and curing are also critical to obtain accurate and representative test results. The research concludes that by following the relevant standards and procedures, it is possible to obtain consistent and reliable results that can be used to assess the quality and performance of concrete in various construction applications. This research provides a useful guide for engineers, contractors and researchers involved in the construction industry to understand and apply the standards for testing the mechanical properties of concrete.

Keywords: ACI, ASTM, European standards, mechanical properties, testing

1. INTRODUCTION

Concrete is the most used material worldwide, surpassed only by water consumption. Concrete production greatly impacts the global economy (Gavilan & Luiz Carlos, 2018). (Miller et al., 2016) calculated the annual concrete consumption of 10,058 million cubic meters. The production of high-quality concrete requires specific knowledge and abilities. From the careful selection of constituent materials and their compatibility through production, placement, and work hardening, a lengthy procedure of trial and testing leads to the conformance evaluation. Depending on the material's nature, laboratories for building materials undertake these tests with varying characteristics, functions, and limits. The mechanical and durability properties of concrete mixtures can be adjusted to meet the design specifications of construction. The compressive strength of concrete is the most common performance measure used by engineers to determine if the concrete is structurally acceptable or not. After the concrete has hardened, it is typically required to examine the structure to verify if it is sufficient for its intended use. Various tests and examinations could be made to check this acceptability. Concrete mechanical properties play the primary control role in concrete quality control and assurance regarding bearing capacity, lifetime and durability. Concrete strength tests are

performed for several reasons (Mindess et al., 2003a). For research purposes, physical laws and properties investigation. During construction, an estimate of the in-situ strength of concrete may be desired for determining the safe time to strip forms or to proceed with further work. The adequacy of mix proportions may need to be verified. And for quality control, part of the quality aspect is the determination of the acceptability of concrete (Neyestani, 2011).

Testing the mechanical properties of concrete is an essential aspect of evaluating the quality and performance of concrete mixes. The mechanical properties of concrete, such as compressive strength, flexural tensile strength, shear strength and modulus of elasticity, are related to the performance and durability of concrete structures and are used to ensure that concrete meets the required specifications. The importance of standardization in concrete testing cannot be overstated. A number of standards have been developed by organizations such as the European Union (EU), the American Society for Testing and Materials (ASTM), and the American Concrete Institute (ACI) to ensure consistency and accuracy in concrete testing. These standards specify the procedures and tolerances for testing the mechanical properties of concrete and are widely adopted in many regions worldwide. European and American consumptions correspond to approximately 9% of this total amount, but their regulations are widely

adopted in many other countries worldwide. Despite the widespread adoption of these standards, comparative studies related to concrete strength testing codes, standards, and specifications are uncommon in the available literature. While several studies have highlighted the European or American standards, with a comparison of testing results, a few studies have considered the difference between those standards, the specimen shapes, the testing conditions, procedures, and the special considerations.

This paper discusses the main variations and differences between testing the compressive strength, flexural tensile strength, and modulus of elasticity of concrete according to EU, ASTM, and ACI standards. It will provide an overview of the testing procedures and requirements specified in each standard and compare the differences and similarities between the standards. Understanding these variations and differences is essential for professionals in the construction industry who use these standards to evaluate the quality of concrete mixes and design concrete structures.

2. TESTING OF THE MOST COMMON MECHANICAL PROPERTIES

2.1 Specimens preparations

The preparation of concrete specimens is a crucial step in evaluating the mechanical properties of concrete and ensuring compliance with the relevant standards. In this regard, several standards have been established as the ASTM C192 (ASTM international, 2002), the ACI 308 and the EN 12390-1 (European Standards, 2003a). These standards outline the procedures and tolerances for the preparation of concrete specimens in the laboratory or on-site, ensuring consistency and reliability in the testing process. Adhering to these standards guarantees accurate evaluation of the properties of the concrete mix and compliance with the relevant specifications for the specific application. Failure to adhere to these standards may result in variations in the preparation of concrete specimens, leading to inconsistent and unreliable test results and potentially the use of substandard concrete in construction. One main difference between these standards is the type of curing methods allowed, with ASTM and ACI allowing for the use of moist rooms, water tanks, and membranes. At the same time, the EU standard also allows for the use of curing compounds and the application of heat. Another difference is the minimum curing time and temperature requirements, with ACI specifying more stringent requirements than the other two standards.

2.2 Curing

Concrete curing is the process of maintaining a moist and favourable environment for the newly placed concrete to allow it to harden properly and gain strength. Several standards specify the procedures and tolerances for concrete curing, including the American Society for Testing and Materials (ASTM), the American Concrete Institute (ACI), and the European Union (EU).

ASTM C31/C31M (ASTM International, 2010) is the standard practice for making and curing concrete test specimens in the laboratory. It covers the procedures for preparing, moulding, curing, and storing concrete specimens and includes provisions for the use of moist rooms, water tanks, or membranes for curing.

ACI 308 (ACI Committee 308, 1998) is the standard for curing concrete in the United States. It includes recommendations for the curing of concrete, including the use of moist rooms, water tanks, or membranes for curing, as well as the use of curing compounds and the application of heat. The standard also specifies the minimum curing time and temperature requirements for different types of concrete (ACI Committee 308, 2016).

The EU standard for curing concrete is EN 12390-2 (European Standards, 2003b). This standard is similar to ASTM C31 and ACI 308, but it includes additional provisions for curing specimens made from lightweight and high-strength concrete.

Despite these differences, all three standards provide a consistent and reliable method for curing concrete. They are widely used in the construction industry to ensure that concrete achieves the required strength and durability. Proper curing is essential for developing the desired properties of concrete, including strength, density, and durability (Felippe & Andrade, 2003; Hamada et al., 2022; Tang et al., 2017).

There are several differences between European standards, (ASTM), and (ACI) standards in the curing specifications for concrete. Some of the differences include the following:

- Curing temperature: European standards generally specify lower minimum curing temperatures compared to ASTM and ACI standards. For example, the European standard EN 206-1 (European Standards, 2013) specifies that concrete should be cured at a minimum temperature of 10 °C (50 °F) for the first 24 hours after casting and that the concrete should not be subjected to freezing temperatures for at least the first 72 hours. On the other hand, ASTM C31 (ASTM International, 2010) Standard Specification for Making and Curing Concrete Test Specimens in the Laboratory and ASTM C192/C192M (ASTM international, 2002) Standard Practice for Making and Curing Concrete Test Specimens in the field specifies that concrete should be cured at a minimum temperature of 16 °C (60 °F) and 23 °C (73.5 °F) respectively for the first 48 hours after casting. The American Concrete Institute (ACI) standard for curing temperature is ACI 308R-01 (ACI Committee 308, 1998), Guide to Curing Concrete, which states that concrete should be cured at a minimum temperature of 20 °C (68°F) for the first 7 days after casting. The concrete curing temperature is important because it affects the rate of hydration and the development of strength in the concrete. The lower the curing temperature, the slower the rate of hydration and the slower the development of strength. High temperatures can cause excessive drying and can also cause cracking. Therefore, it is important to maintain proper curing temperatures in order to achieve the desired strength and durability of the concrete.
- Curing duration: The European standard EN 206-1 specifies that concrete should be cured for at least 28 days before it is subjected to any mechanical loading, this is to ensure that the concrete has reached its maximum strength and that the structure is safe to use. On the other hand, the ACI 308R-01, stated that concrete should be cured for a minimum of 7 days before being subjected to mechanical loading. ASTM C31 and ASTM C192, do not specify any minimum curing duration for concrete before it is subjected to mechanical loading, but provide guidelines for making and curing concrete test specimens in the laboratory and field, respectively.

The curing duration is important because of the

concrete strength gained during the curing period, it is also important for the development of the concrete's microstructure and also for reducing the risk of cracking. The more the curing duration, the more strength gained and the more the development of the concrete's microstructure. Proper curing is crucial to achieve the desired strength and durability of the concrete.

- Curing methods: The European standard EN 206-1 provides several options for curing concrete, it allows for curing using various methods such as: keeping the concrete wet using water, covering the concrete with water-retaining materials such as plastic sheets, covering the concrete with wet burlap or other water-retaining materials, continuously misting the surface of the concrete or using any other method that will effectively keep the concrete surface moist and at a temperature above 10 °C. On the other hand, ASTM C31 and ASTM C192/C192M, do not specify any specific curing methods, but they do require that the concrete be cured in a moist condition, either by ponding or by covering the concrete with a moisture-retaining material, such as plastic sheeting. The ACI 308R-01 stated that concrete should be cured in a moist condition, either by ponding or by covering the concrete with a moisture-retaining material, such as plastic sheeting or by maintaining a humidity chamber around the concrete, it also allows for the use of curing compounds, which are liquid-applied or spray-applied materials that can be applied to the surface of freshly placed concrete to form a barrier that slows or prevents the evaporation of water from the concrete surface, which promotes the hydration process of the cement.
- Acceptance criteria: The European standard EN 206-1 specifies several acceptance criteria for cured concrete, including strength, density, air content, workability, and durability. The standard also establishes requirements for surface quality, such as allowable tolerances for surface defects and requires the concrete to be free from harmful substances that could negatively impact the properties of the concrete over time. On the other hand, ASTM C31 and ASTM C192, provide specific requirements for compressive strength, air content, workability, density and durability of the concrete, but do not include specific requirements for surface quality. The acceptance criteria are standards ACI 308R-01, stated that concrete should be inspected and tested to ensure that it has achieved the desired strength and durability properties, it also specifies a compressive strength requirement and air content requirements but does not specify other requirements for surface quality and durability as the European standards do.

2.3 Compressive strength

Compressive strength tests for concrete are essential for evaluating the quality and performance of concrete mixes. Additionally, the grading of concrete often relies on its characteristic compressive strength e.g. C20/25 (Tam et al., 2017). By emphasizing the compressive strength as the nominal way to characterize concrete, it highlights the significance of this property in assessing the quality and performance of the material. These tests determine the compressive strength of concrete, which measures the material's ability to resist compressive loads. The compressive strength of concrete is a critical property for determining the structural suitability of the material for its intended use (Aghda & Baniasadzade, 2013; Mindess et al., 2003a; G. B. Neville, 2012; Neyestani, 2011).

Compressive strength tests are performed on cylindrical or cubic concrete specimens of a specific size and shape. The specimens are typically made from fresh concrete and cured in a controlled environment before testing. The compressive strength of the concrete is determined by applying a compressive load to the specimen until it reaches failure. The compressive strength of concrete is directly related to the performance and durability of concrete structures. A concrete mix with high compressive strength will withstand greater loads and be more durable over time than a mix with lower compressive strength. This is important for ensuring that concrete structures are safe and will perform as intended over their intended lifespan. In addition, the compressive strength of concrete is used to evaluate the material's suitability for different types of construction projects. Different types of projects have different requirements for the compressive strength of concrete, and compressive strength tests are used to ensure that the concrete mix meets these requirements. For example, the compressive strength of concrete used in high-rise buildings or bridges must be much higher than that of concrete used in sidewalks or residential foundations.

Compressive strength tests are also used to verify the adequacy of mix proportions (Talaat et al., 2021) and to estimate the in-situ strength of concrete during construction (Gavilan & Luiz Carlos, 2018). This information is used to make decisions about when it is safe to strip forms or proceed with further work on a structure. It also provides insight on the quality control of the concrete and the acceptance criteria for the concrete mixture. The concrete industry relies heavily on the results of concrete compressive strength tests to determine the adequacy of as-delivered or in-place concrete. Compressive strength tests provide a good and straightforward indication of assessing the property of the concrete in its hardened state. Specimens of various shapes and sizes are used to determine the compressive strength of the concrete (Abd & Habeeb, 2014; *Comparison of Test Methods of Evaluation of Concrete Durability in the Persian Gulf Environment*, 2013; Kumar et al., 2016). The specimen size and shape are different in the available authorized standards. Several standards specify the methods and tolerances for this type of testing, including the (ASTM), the (ACI), and the European Union (EU).

ASTM C39/C39M (ASTM International, 2018) is the standard test method for determining the compressive strength of cylindrical concrete specimens. The test involves placing a cylindrical concrete specimen in a compression-testing machine and applying a compressive load to the specimen until it fractures. The compressive strength is calculated by dividing the maximum load achieved during the test by the cross-sectional area of the specimen.

ACI 318 is the standard for the design and construction of reinforced concrete in the United States. It includes provisions for determining the compressive strength of concrete, including cylinders and cubes. The standard specifies the size, shape, and manufacture of the specimens, as well as the testing procedure and the calculation of the compressive strength.

In the EU, the standard for testing the compressive strength of concrete is EN 12390-3 (European Standards, 2019a). This standard is similar to ASTM C39 (ASTM International, 2018) and ACI 318 (ACI 318, 2020; ACI Committee 311, 2004a), but it includes additional provisions for preparing, curing, and testing specimens made from lightweight and high-strength concrete.

One main difference between these standards is the size

and shape of the specimens used for testing. ASTM and ACI specify the use of cylinders, while the EU standard allows for cylinders or cubes. Another difference is the size of the specimens, with the EU standard allowing for larger specimens than ASTM and ACI, as explained in the following.

There are several differences in the compressive strength testing procedures and acceptance criteria specified by European and American standards. Some of the differences include the following:

- Testing frequency: European standards generally specify a higher testing frequency than American standards. For example, European standards for concrete specify that compressive strength testing must be performed at 7 and 28 days after the concrete is poured, while American standards typically only require testing at 28 days. This means that the concrete's strength is checked twice in Europe but only once in the US. This difference in testing frequency may be due to the fact that European standards tend to place a greater emphasis on ensuring the quality and safety of construction materials, while American standards may focus more on cost-effectiveness and efficiency (Technical Activities Committee, 2022). It's worth noting that this is just one example, and the specific testing requirements can vary depending on the product or material and the standard being used (ACI Committee 311, 2004a).
- Test specimen size: European and American standards specify different sizes for the concrete test specimens used for compressive strength testing. European standards generally define smaller test specimens compared to American standards. According to European standards (European Standards, 2019a), the concrete test specimens for compressive strength testing are generally cylindrical in shape with a diameter of 150 mm and a height of 300 mm, as shown in Fig 1, or cubes with 150 mm side size as shown in Fig 2. On the other hand, American standards generally define slightly larger concrete test specimens for compressive strength testing. According to American standards, the concrete test specimens are cylindrical in shape with a diameter of 6 inches (152.4 mm) and a height of 12 inches (304.8 mm). These specimens are referred to as 6x12 inches cylinders (ASTM international, 2009) It is important to note that the size of the test specimens can affect the compressive strength test results. Smaller test specimens generally have lower compressive strength values compared to larger specimens. This is because smaller specimens are more susceptible to variations in their manufacturing process and have less material to average out any variations in the strength of the concrete (Abd & Habeeb, 2014; Domagala, 2020; A. M. Neville, 2012; Sudin & Ramli, 2014; To et al., 2005).
- Testing machine capacity: European standards generally specify lower capacities for the testing machines compared to American standards. According to European standards, the capacity of the testing machine for compressive strength testing of 150 mm concrete cubes should be at least 2,500 kN (560,000 lbs). This capacity is sufficient to test concrete cubes with compressive strength up to around 150 MPa (22,000 psi). While American standards generally specify higher capacities for the testing machines. According to American standards, the capacity of the testing machine for compressive strength testing of 6x12 inches of concrete cylinders should be at least 11,000 kN (2,500,000 lbs). This capacity is sufficient to test concrete cylinders with compressive strength up to

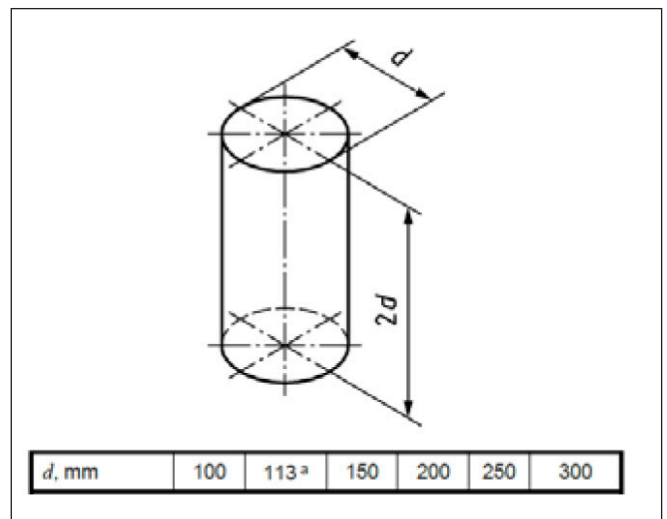


Fig 1: Standard cylindrical specimen shape size (European Standards, 2019a)

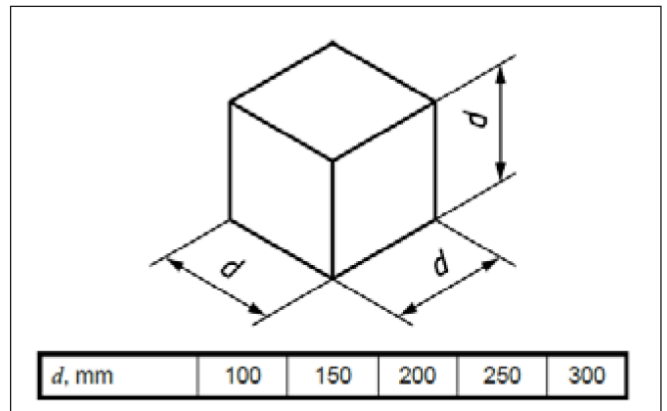


Fig 2: Standard cubic shape size (European Standards, 2019a)

around 150 MPa (22,000 psi). It's important to note that the capacity of the testing machine is a critical factor in determining the accuracy of compressive strength test results (Kumar et al., 2016; Talaat et al., 2021). A testing machine with a lower capacity than the maximum strength of the specimen will not be able to accurately determine the compressive strength of the specimen. The difference in testing machine capacities between European and American standards can be attributed to the different sizes of the concrete test specimens used in the two regions. As previously mentioned, European standards generally define smaller test specimens compared to American standards, and thus lower capacity testing machines are sufficient for testing these smaller specimens.

- Acceptance criteria: European standards generally define higher minimum compressive strength values for normal-weight concrete compared to American standards. According to European standards, the minimum compressive strength for structural concrete should be at least 20 MPa (2,900 psi) and at least 25 MPa (3,600 psi) for precast and prestressed concrete. These values apply to concrete that has reached 28 days of age and is cured under standard curing conditions. Comparing with the American standards, which define lower minimum compressive strength values for normal-weight concrete. According to American standards, the minimum compressive strength for residential and non-residential construction should be at least 2,500 psi (17 MPa) and at least 3,500 psi (24 MPa) for bridges and other infrastructure. These values also apply to concrete that has reached 28 days of age and is cured under standard curing conditions.

2.4 Flexural tensile strength

Flexural strength, also known as bending strength, is an important mechanical property of concrete that measures its ability to resist bending loads. It measures the concrete's ability to resist bending loads; when a load is applied to the top of the beam, the bottom will bend. The flexural strength of concrete is crucial for determining the suitability of the material for construction projects that involve beams or slabs that are subject to bending loads (Mindess et al., 2003b; A. M. Neville, 2012; G. B. Neville, 2012). Flexural strength tests are typically performed on beam-shaped concrete specimens of a specific size and shape. The specimens are typically made from fresh concrete and cured in a controlled environment before testing. The flexural strength of the concrete is determined by applying a load to the top of the beam and measuring the bending of the bottom of the beam (Carpinteri, 1992; Popovics, 1992; Shetty & Jain, 2019). It's also a significant property for evaluating the durability of concrete structures. Concrete structures subjected to repeated loading and bending can experience cracking and deterioration over time if the concrete's flexural strength is insufficient. Therefore, it's crucial to have appropriate flexural strength to ensure the safety and longevity of the structure (Wang & Gupta, 2021). In addition, flexural strength tests are also used to verify the adequacy of mix proportions, estimate concrete's in-situ strength during construction, and evaluate the material's suitability for different types of construction projects (Seyam & Nemes, 2022a). The results of flexural strength tests and other mechanical properties are used in the design and construction of concrete structures to ensure that they can withstand the loads to which they will be subjected. Several standards specify the procedures and tolerances for flexural strength testing, including the American Society for Testing and Materials (ASTM), the American Concrete Institute (ACI), and the European Union (EU).

ASTM C78 (ASTM International, 2016) is the standard test method for flexural strength testing of concrete. It involves using a three-point bending test on a concrete beam specimen with a span length of at least twice the depth. The flexural strength is calculated by dividing the maximum bending moment achieved during the test by the beam's section modulus; in addition, ACI 318 (ACI 318, 2020; ACI Committee 311, 2004b) is the standard for the design and construction of reinforced concrete in the United States. It includes provisions for determining concrete's flexural strength, including the three-point bending and four-point bending tests. The standard specifies the specimens' size, shape, and manufacture, as well as the testing procedure and the calculation of the flexural strength. In the EU, the standard for testing the flexural strength of concrete is EN 12390-5 (British Standards Institution (BSI), 2019). This standard is similar to ASTM C78 and ACI 318, but it includes additional provisions for preparing, curing, and testing specimens made from lightweight and high-strength concrete. One main difference between these standards is the size and shape of the specimens used for testing. ASTM and ACI specify the use of beams, while the EU standard allows for the use of beams or prisms. Another difference is the type of test used, with ACI allowing for both three-point and four-point bending tests, while the EU standard only provides for three-point bending.

There are notable differences among the European, ASTM, and ACI standards regarding the flexural strength testing of concrete. Some of the differences include the following:

- Test specimen size: European, ASTM, and ACI standards specify different sizes for the concrete test specimens used for flexural strength testing. European standards generally specify smaller test specimens compared to ASTM and ACI standards. European standards, such as those set by the European Committee for Standardization (CEN), generally specify smaller test specimens compared to ASTM and ACI standards. The size of the test specimens used in European standards is typically 150 mm x 300 mm x 600 mm (length x width x height). These smaller test specimens are often used in the laboratory, rather than in the field, to determine the flexural strength of concrete. On the other hand, ASTM (American Society for Testing and Materials) and ACI (American Concrete Institute) standards typically specify larger test specimens, such as 150 mm x 150 mm x 700 mm or 150 mm x 150 mm x 900 mm. These larger test specimens are often used in the field to determine the flexural strength of concrete in situ. It is important to note that the flexural strength of concrete, also known as the modulus of rupture, measures the material's ability to resist failure in bending. The size and shape of the test specimen can affect the measured flexural strength, so it is important to use the appropriate specimen size and shape when conducting flexural strength tests to ensure that the results are accurate and comparable.
- Testing machine capacity: European standards, such as those set by the European Committee for Standardization (CEN), generally specify lower capacity for testing machines than ASTM and ACI standards. For example, the European standard EN 12390-4 specifies a capacity of 2000 kN for testing machines used to determine the flexural strength of concrete. This lower capacity is sufficient for testing the smaller test specimens typically used in European standards. On the other hand, ASTM and ACI standards typically specify higher capacities for testing machines, such as 4000 kN or 6000 kN. These higher capacities are often required to test the larger test specimens typically used in ASTM and ACI standards.

It is important to note that the capacity of a testing machine refers to the maximum force it can apply to a test specimen. The capacity of the testing machine should be greater than the expected strength of the specimen being tested, to ensure that the results are accurate and reliable. Also, the codes and standards have different requirements for the capacity of the testing machine depending on the requirements for the test and the type of specimen used.

- Testing procedures: European, ASTM, and ACI standards specify different methods for conducting flexural strength testing. For example, European standards may specify the use of a three-point bend test, while ASTM standards may specify the use of a four-point bend test. The European standard for flexural strength testing is EN 12390-5 (British Standards Institution (BSI), 2019), which specifies the use of a two-point loading bend test. In this test, a beam specimen is supported on two rollers that are located at a fixed distance apart, and a load is applied from the top by two loading points as shown in *Fig 3*, the EN 12390-5 standards added the center point loading to their specification, where a beam specimen is supported on two rollers that are located at a fixed distance apart and loaded by a third point, usually at the midpoint of the specimen as shown in *Fig 4*. The load is applied in such a way that it bends the specimen in a single plane. The flexural strength of the specimen is determined by measuring the maximum load that the specimen can withstand before it fails in a brittle manner.

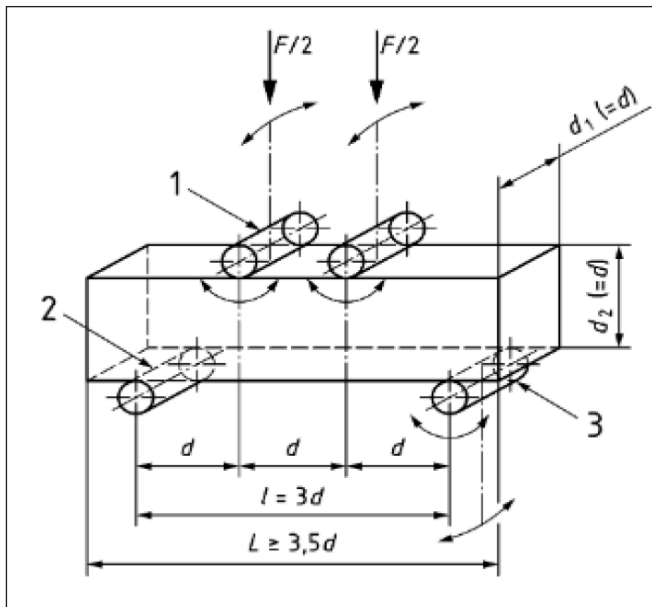


Fig 3: Two point loading for flexure test of concrete based on European standards (European Standards, 2019b)

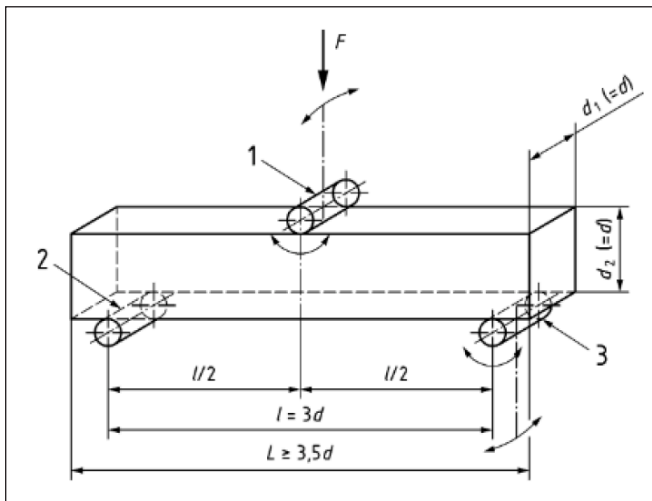


Fig 4: Central point loading for flexure test of concrete based on European standards (European Standards, 2019b)

The American Society for Testing and Materials (ASTM) has several standards for flexural strength testing, including ASTM C78, ASTM C293, and ASTM C496. ASTM C78 standard specifies the use of a four-point bend test, shown in Fig 5, in which a beam specimen is supported on two points at one end and two points at the other end. A load is applied at the midpoint of the specimen, in such a way that it bends the specimen in a single plane. As the test is done with 4 points of support, it is more accurate in a case where there are some non-uniformities in the sample.

The American Concrete Institute (ACI) standard for flexural strength testing is ACI 318-19. The standard describes two methods for determining the flexural strength of concrete: the simple beam with centre-point loading and the modified two-span beam test. The simple beam test is similar to the three-point bend test described in the European standard, while the modified two-span beam test is similar to the four-point bend test described in the ASTM standard. It's worth mentioning that each standard can have several variations in procedure, but the general principle of testing is the same.

Despite these differences, all three standards provide a consistent and reliable method for determining the flexural strength of concrete. They are widely used in the construction industry to ensure that materials meet the required strength

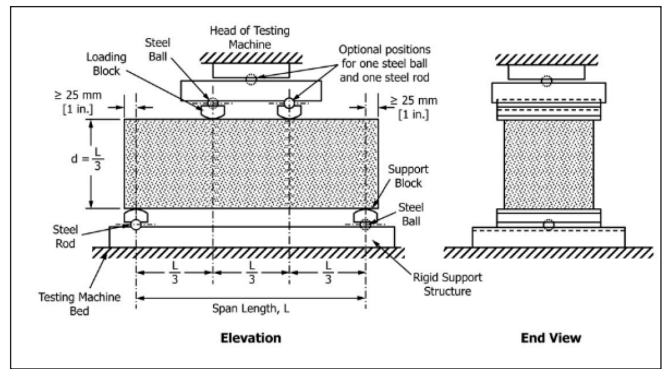


Fig 5: Apparatus for Flexure Test of Concrete based on ASTM C78 (ASTM International, 2016)

requirements and to evaluate the quality of concrete mixes. The flexural strength of concrete is an essential factor in the design of structures, as it determines the material's ability to resist cracking and deformation under load.

2.5 Shear strength

Shear strength, also known as the transverse strength of concrete, is an important mechanical property that measures a concrete's ability to resist shear loads (Lamond & Pielert, 2006; Popovics, 1992). It is the ability of the concrete to withstand forces that are applied perpendicular to the main axis of the material. Shear strength of concrete is a critical property for determining the structural suitability of the material for certain types of construction projects, particularly those that involve the use of beams or slabs that are subject to shear loads. Shear strength tests are typically performed on concrete beams, typically by applying a transverse load to the beam, and measuring the deformation of the beam. Several methods can be used to test the shear strength of concrete, such as the beam shear test, the diagonal compression test, or the direct shear test. The shear strength of the concrete is determined by the ratio of the applied load to the beam's shear deformation (G. B. Neville, 2012; Ozyildirim & Carino, 2006; Popovics, 1992; Shetty & Jain, 2019). Shear strength also plays an important role in the durability and safety of concrete structures. Concrete structures that are subjected to repeated loading and shear forces can experience cracking and deterioration over time if the shear strength of the concrete is not sufficient. The shear strength is an essential property to ensure the safety and longevity of the structure. In addition, shear strength tests are also used to verify the adequacy of mix proportions and estimate concrete's in-situ strength during construction (Seyam & Nemes, 2022b). There are several methods for testing the shear strength of concrete, including the direct shear test, the beam shear test, and the diagonal compression test (Slater et al., 1926). The American Concrete Institute (ACI) 318-19, Building Code Requirements for Structural Concrete, provides provisions for the design of members and systems that resist shear forces, but it doesn't provide methodologies or procedures for testing the shear strength of concrete. The American Society for Testing and Materials (ASTM) does not have any specific standard for shear strength testing of concrete. EN standards as well as does not have a specific standard for shear strength testing of concrete. Different countries or regions may have different standards and codes for shear strength testing of concrete.

2.6 Modulus of Elasticity

The modulus of elasticity, also known as Young's modulus, is a key mechanical property of concrete that measures a

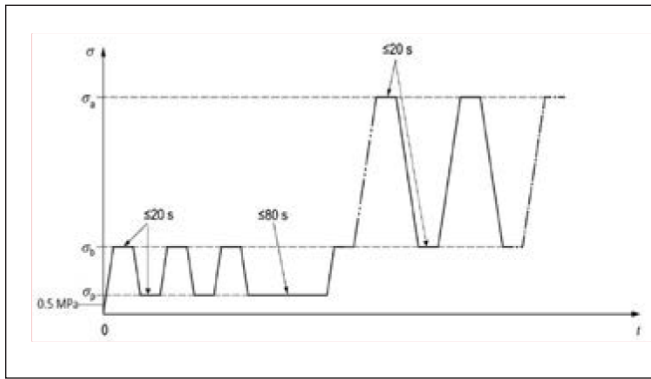


Fig 6: Cycle for the determination of the modulus of elasticity based on Method A (European Standards, 2013)

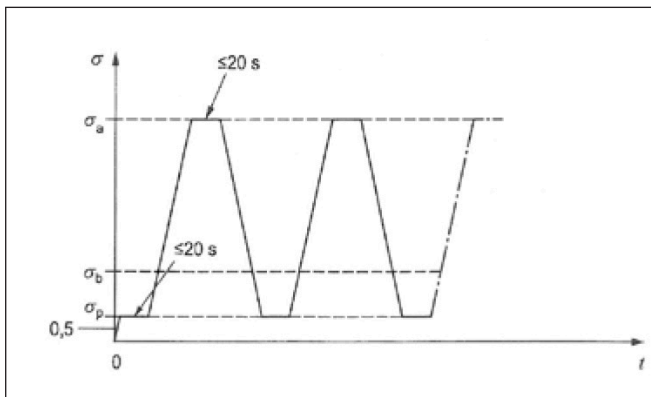


Fig 7: Cycle for the determination of the modulus of elasticity based on Method B (European Standards, 2013)

material's ability to resist deformation under load. It is used in the design of concrete structures to calculate the amount of deformation or strain that will occur under a given load. To determine the modulus of elasticity of concrete, American standards ASTM provide a standards C468/468M (ASTM international, 2014), while the European standards EN 12390-13 (European Standards, 2013) describe the modulus of elasticity methods, tests are typically conducted on concrete cylinders or beams in both compression and tension modes. In compression testing, a load is applied to the cylinder axially to measure the deformation. In tension testing, the load is applied to the end of a concrete beam to measure the deformation. The modulus of elasticity is then calculated as the ratio of the applied load to the corresponding deformation.

A higher modulus of elasticity indicates a higher quality concrete that is less prone to deformation under load. According to (ACI) and (ASTM) standards (ASTM international, 2014), the static modulus of elasticity of concrete is typically determined using cylindrical specimens, while in the European standards, the specimen can be a cylindrical or prismatic shape (Vu et al., 2021), and calculated using the formula $E = P/\Delta$, where E is the modulus of elasticity, P is the applied load, and Δ is the measured deformation. However, neither ACI nor ASTM standards specify a minimum modulus of elasticity for concrete. Similarly, European standards do not specify a minimum modulus of elasticity for normal-weight or lightweight concrete. However, EN 12390-13 standard accepts two methods for the determination of concrete modulus of elasticity: Method A shown in Fig 6. and Method B, shown in Fig 7. Method A is a more detailed and accurate method for determining the modulus of elasticity of concrete. The main difference between Method A and Method B is the manner in which the load is applied. In Method A, the load is applied at a constant rate, while in Method B, the load is applied at a constant rate of deformation. This means

that in Method A, the load is applied at a constant rate until failure occurs, while in Method B, the load is applied until a specified amount of deformation is reached (Domagała & Dobrowolska, 2018).

In addition to static modulus of elasticity, the dynamic modulus of elasticity of concrete can be determined by conducting a resonant frequency test or a pulse velocity test (Trifone, 2017). In the resonant frequency test, the frequency of a vibrating concrete specimen is measured to calculate the modulus of elasticity. In the pulse velocity test, the speed of a pulse of energy transmitted through the concrete specimen is measured to calculate the modulus of elasticity (Henrique Alves & Lucas Barcelos Otani, 2022). These tests are similar to the methods specified in ASTM standards but are not specified in European standards.

3. CONCLUSION

In conclusion, this research has compared the European standards, the American Society for Testing and Materials (ASTM) and American Concrete Institute (ACI) standards for testing the mechanical properties of concrete. The study has highlighted the importance of compressive strength, flexural tensile strength, shear strength, and modulus of elasticity as key properties for assessing the quality and performance of concrete. The research has also revealed that there are variations in the specimen size, preparation, and curing requirements, as well as testing procedures and acceptance criteria among the European, ASTM and ACI standards. The research concludes that it is essential to follow the appropriate standards and testing procedures to ensure the test results' reliability and accuracy. Proper specimen preparation and curing are also critical to obtain accurate and representative test results. By following the relevant standards and procedures, it is possible to obtain consistent and reliable results that can be used to assess the quality and performance of concrete in various construction applications.

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