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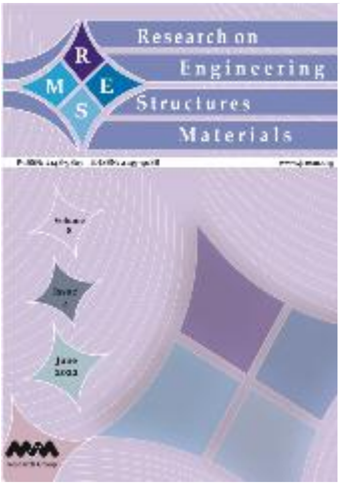

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Review Article

Effect of various interface bond tests and their failure behavior on substrate and overlay concrete -A Review

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Abstract

Concrete is a widely used building material in the construction sector. Still, the lifespan of concrete is limited because many factors can influence the performance of concrete structures, which can be classified based on physical, chemical, and mechanical changes that occur during their service life. In addition, the structure's lifespan is being reduced due to adverse environmental conditions and loads. These require maintenance, restoration, or reconstruction. Therefore, considerable concrete remediation is necessary, and the best option is to repair it. However, the cost associated with restoring the deteriorating concrete structures is higher. The repaired concrete strength mainly depends on the interface layer, situated between the substrate (old) and overlay (new) concrete. The interface layer strength primarily depends on interface adhesion, friction, aggregate interlock, bonding agent, compaction, cleanliness, moisture content, concrete age, roughness, and time-dependent variables. Multiple tests are available to analyse the bonding behavior between substrate-overlay concrete. However, no particular method is available to access the bond strength. This paper describes various methods and techniques used by researchers to evaluate bond strength. The reviewed summary has shown that concrete repair is the best solution, and higher-strength concrete uses show better shear results; also, conventional concrete is more economical than higher-strength concrete. Among all the available tests the bi-surface shear test and slant shear test are the more suitable method to determine the bond strength.

1. Introduction

The interfacial bonding between damaged concrete structures and newly applied repair materials is one of the significant issues for the structure functionality, safety, and durability. At the interfaces of the concrete, a strong bond is required to make it stronger and prevent failure. There are millions of old buildings in Indian cities in degrading condition. These structures create a problem for individuals and their properties (1). For example, 14,375 and 10,500 old structures in Mumbai main city and suburban, respectively, require restoration, but, the reconstruction cost is higher. However, it can be overcome by repairing the existing structure. The repairing cost mainly depends on the old concrete properties, like the type of concrete, compressive strength, age of concrete, or other environmental conditions such as freeze-thaw weathering (2), temperature change, creep, shrinkage, fatigue, etc. Rehabilitation and repair enhance the life of degraded concrete structures by using new concrete because the old concrete cannot regain strength near the fresh concrete. The major factors involved in the bond strength are Van Der Waals (VDW) force and mechanical interlocking, which are mainly influenced by the bonding, the shrinkage difference, and interface roughness of substrate-overlay concrete(3–6). The

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interface layer is the main area of concern because it is a very weak part of the bonding [7]–[11], and the bonding mechanism diagram has been shown in Fig. 1.

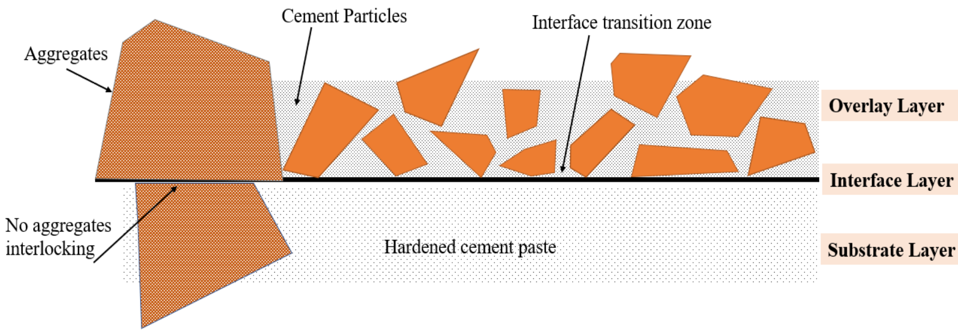

Fig. 1 Substrate-overlay concrete mechanical interlocking (7)

The bond between the substrate and overlay depends on the interface layer. In the bond mechanism, VDW forces, surface profile-related frictional interlock and exposed aggregate-induced mechanical interlock play an important role(8).The interface bond always depends on the chemical, mechanical or physical relation by the formation of the new layer as the interface. Based on the existence of the layer location the substrate–overlay composite is divided into three layers. Based on the scale these are termed macro-scale, mesoscopic and microscopic and the bond mechanics has been shown in Fig. 2. The newly formed gel is present in form of three layers.

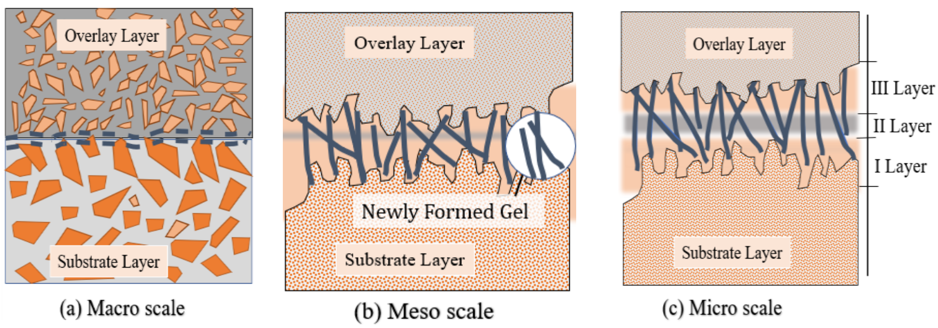

Fig. 2 Scale representation of the interface between substrate-overlay concrete (7)

- I layer–is also known as the penetration layer and it consists of mainly spike types calcium silicate hydrate (C–S–H) with smaller amounts of $Ca(OH)_2$, which is generated within the concrete substrate and contains young ingredients that react with active chemical components in the substrate concrete.
- II layer - it is also known as the highly affected layer or weakest layer; this layer is characterized by high porosity and highly oriented crystal constituents.
- III layer - it is also known as lower impacted layer or lower affected layer, which has almost the same micro-structure as overlay concrete.

From Fig. 2, it is clear that the surface roughness and presence of microcracks also affect the hydration product chain. Wang et al. (9) defined the chemical behavior of the OPC-based repair materials through the C-S-H gels process and stated that the chemical creates adhesion to the concrete substrate. Other than this various factors are involved in standardizing the bonding test procedure, such as the loading condition, interface layer behavior, and geometry (10). Unfortunately, there is no suitable method to evaluate the accurate bond strength of the interface (11). However, some studies have recommended the tests mentioned below to estimate the bond strength between substrate and overlay concrete (11–13).

2. Objective of the Study

The primary objective of this research was to find out the suitable bond strength test of substrate and overlay concrete. Also, an effort has made to find the relation among the studied tests, different geometry and material properties. The failure patterns based on stress condition is also expected.

3. Literature Study

In this section, the test procedures and methods for evaluating interface bonding have been discussed. In real life, the interfaces between concrete layers are usually loaded in pure shear mode, pure tension mode, shear-compression mode, and shear-tension mode. The related geometry used in various tests and their shape have been shown in Table 1 and Fig. 3 respectively.

3.1 Direct and Indirect Tension Tests (Pure Tension)

These tests are useful for carrying out the bonding behavior between the substrate and the overlay concrete. In these tests, stress is determined by the effect of pure shear (14)(15). Various tests and their loading conditions have been described below.

3.1.1 Pull Off Test (POT)

It is suitable for assessing bond strength in the field and the laboratory. Because of its simplicity, many codes of practice recommended this test for quality assessment. This test applies a direct tensile force on an interface layer; but, this test method is complex due to several factors, such as damage by drilling, inappropriate gluing of the loading disc, system misalignment, interface geometry, and related stress disturbance. These types of complexity cause substrate failure. The testing guidelines are given in the ICRI code (16), and the test setup has been shown in Fig. 3(p). The minimum requirement for pull-off strength according to ACI 546-06 is 1.7-2.1 MPa at 28 d. Julio et al. (17) showed a strong relationship between the SST and POT; however, Yildirim et al. (18)stated no correlation between these two methods. Fig. 4 shows the relationships discovered by Julio et al. (17) and Yildirim et al. (18) with slant shear strength and pull-off strength. The difference between the SST and POT bond strength can be seen directly in Fig. 4 due to the various parameters, such as loading rate, differential shrinkage magnitude, specimen size, testing apparatus, etc. Some researchers used various types of materials to analyze the pull-off strength.

Thongchom et al. (19) investigated the effect of higher temperature on POT bonding and found that the bond strength and fracture energy reduced due to high temperature. The main disadvantage of this test is that the specimen gest partly destroyed during testing and the complexity of bonding. Further research is needed to resolve this issue. POT bond strength can be seen directly in Fig. 4 due to the various parameters, such as loading rate, differential shrinkage magnitude, specimen size, testing apparatus, etc. The expected failure mode have been shown in Fig 7(a) with loading diagram for POT.

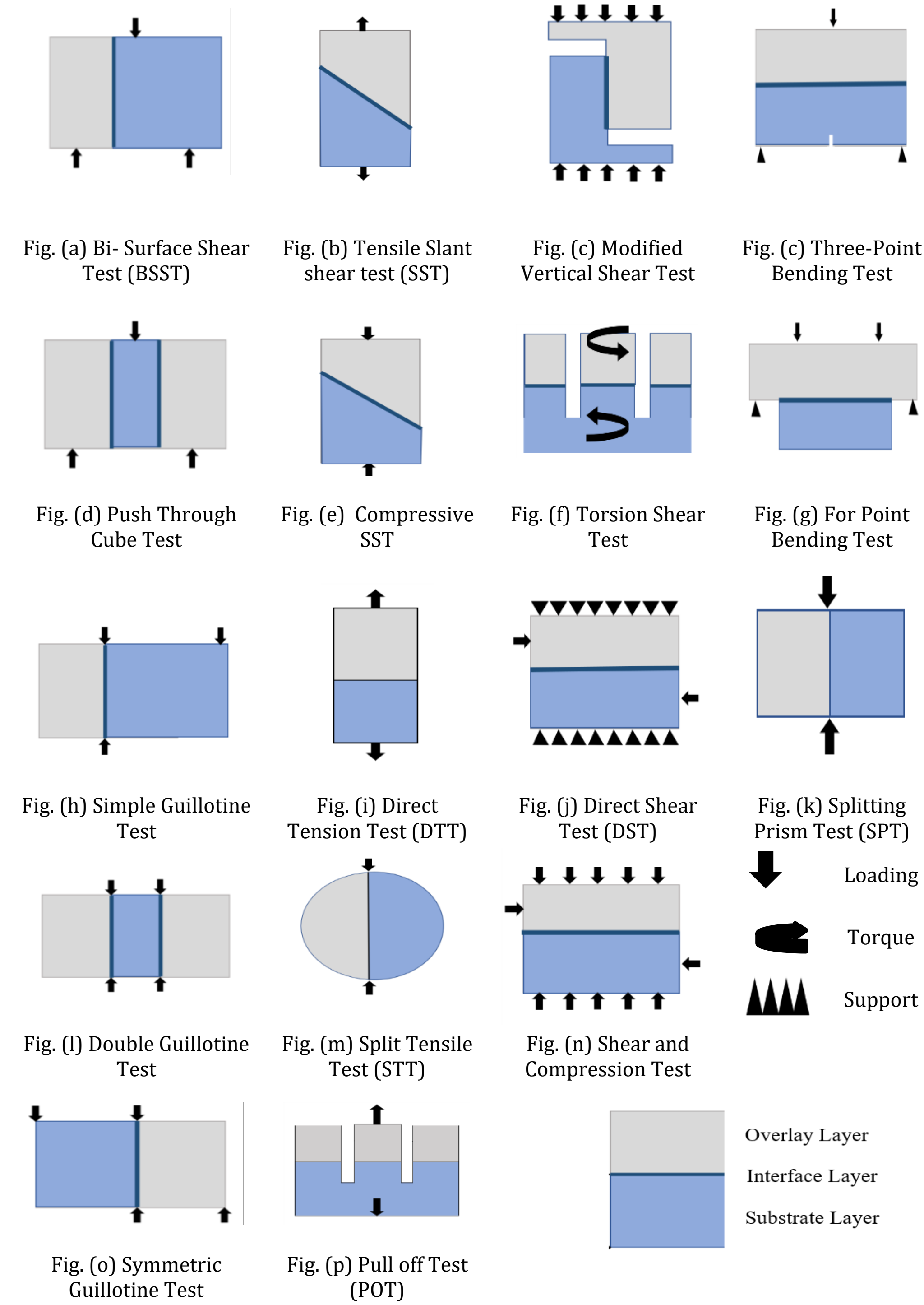

Fig. 3 Specimen shapes of various tests with loading conditions (15)

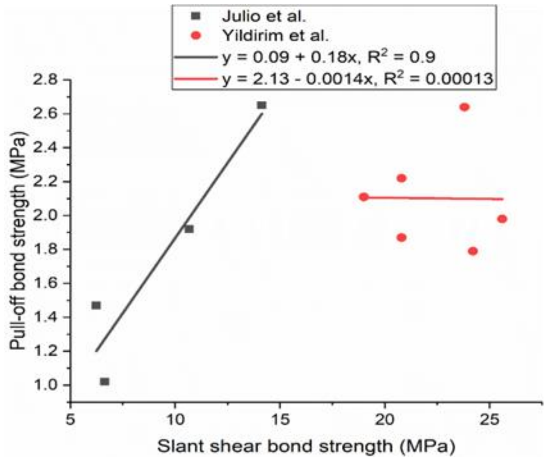

Fig. 4 Relationship between SST and POT (17)(18)

3.1.2 Direct Tension Test

This test examines the tensile bond strength between substrate and overlay material. In this test, two opposite tensile stresses are applied using two steel plates to a composite specimen. The test setup has been shown in Fig. 3(i). The expected failure mode have been shown in Fig 7(b) with loading diagram for DTT. There is no specific provision in American Society for Testing and Materials (ASTM)78 (20) to determine direct tensile strength. However, ASTM C 496 shows the procedure of splitting tensile strength measurement (21). Kim et al. (22) stated that comparing tensile and shear bond strength is challenging but usually related.

3.1.3 Splitting Prism Test

To determine the tensile strength of prismatic specimen STT is used, and the test setup has been shown in Fig. 3(k). According to ASTM C 496 (21), this test is good to determine the interface bond strength; but, some factors can influence the test technique, such as the freezing and thawing of specimens (23)**.**

Table 1. Various interface bond tests and their geometry

Test Name	Size of tests
POT	40×40×160 (Cohesive and mixed failure)(32) 150×150×150 φ (14) 300×300×70 (Substrate failure) (10) 35×50 and 110×50 with α= 180° (33) 300×650×80 (Overlay failure) (34) 600×800×100 and 500×500×70 (35)
DTT	100×100×300 (Partial interface failure) (13) Φ=100,h=200 (Cohesive and mixed mode) (36)
Splitting prism/ Cylinder test	150×50with α= 180° and 200×100 with α= 0° (33) Φ = 100, h=200and 40×40×160 (37)
Splitting cylinder test	Φ = 100 h= 200 (Substrate failure) (10) 100×100×100 and 100×100×400and φ = 160, h= 320 (Interface failure and Mixed failure) (38)
BSST	150×50, h= 150 (Substrate Failure) (14) 40 ×40 ×160 (39)

	50×150×150 and 100×150×150 (Adhesive, Cohesive and Mixed failure) (40) 38 ×51 × 153 (Mixed failure) (41) 50×150×150 (Shear failure) (24)
Modified vertical shear test	150×150×600 with α= 30° (12) 300×150×300 (33) 100x100x300 (Cohesive failure) (36) 150×150×150 (Close to interface) (42) 254×546×127 (At connectors failure) (43)
SST	102×76×394 with α=60° and 70° (Cohesive and mixed failure) (32) 100×100×300 (Substrate Failure)(10) 75×150 α= 42° (Within the substrate) (11) 75x150 α= 30° (37) Φ= 150 α= 30° h= 300, φ = 75 30° h= 150 , 100x100×400, 200x200×100 (With Epoxy no interface failure) (44) 75 ×150, α = 30° (45)
Flexural Bond test	150×150×500 (Mixed failure) (11) 100×100×400 (Shearing failure) (39) 100×100×500, 100×100×250 (Interface failure)(46)

Where, φ – Diameter of specimen, h- Slant height and α is slant angle. All dimension are in mm.

The expected failure mode has been shown in Fig 7(d) with loading diagram for SPT. According to Momayez (14) and Ju et al. (24), this test is more suitable to find bond strength; The test procedure is simple and utilizes the same specimen for the BSST and the loading procedure is simple for the split cylinder test. Zhang et al (25) recommended this test for actual engineering application with the use of 5 to 20 mm size gravel, which improve the bond strength by nearly 24%; but, Pedro Miguel Duarte Santos (26) stated that the SPT is inappropriate to determine the bond strength and further recommended investigation at later age.

Some authors (25,27–29)found the split bond strength with different sizes of gravel, surface patterns and different overlay materials. With the use of the gravel patterns, the bond strength was increased by 60.3% as compared to the chipped surface (30). Bond strength testing of split prism specimens was performed using a modified version of ASTM C496, with results of 1.5 MPa for the 0.05 mm texture and the bond strength was nearly 3.7 MPa for the rough texture (31).

3.1.4 Splitting Cylinder Test

A simple cylindrical specimen is used to determine the tensile bond strength. This test is easy to perform on composite material, and the test setup has been shown in Fig. 3(m). The procedure for the above test is as per ASTM C1404 (47) and ASTM C1583 (48). In this test, the interface layer is more critical. It is affected by impact loading that causes various types of failure due to damage at the interface (49); but, is unaffected by the surface preparation as per International Concrete Repair Institute (ICRI) 210.3 (50) classification. The expected failure mode have been shown in Fig 7(c) with loading diagram for pure tensile bond test.

According to Hu et al. (49), the Split tensile bond strength of the composite section is related to the compressive strength and split tensile strength of old and new concrete. Zhu et al. (51) recommended a factor of 0.738 for compressive strength and 0.96 for splitting tensile strength to convert cubic strength to cylindrical strength for steel fibre reinforced concrete. The STT (Brazilian test) can be used to estimate a repair cementitious failure envelope more efficiently (52).

Qian et al. (53) found that the splitting tensile strength did not change significantly after 150 d freeze-thaw cycles for substrate concrete. According to Tayeh et al. (54), the bond strength was unusually high in this case. Due to the simplicity of this test, some researchers performed the STT on composite cubes (55), prisms (51), or cylinders (56) to evaluate the correlation between various tests. Michael and M. Sprinkel (57) described the tensile bond strength into five groups, shown in Table 2.

Table 2. Split tensile bond strength classification based on bond strength (57)

Strength (MPa)	≥ 2.1	1.7-2.1	1.4-1.7	0.7-1.4	0-0.7
Category	Excellent	Very good	Good	Fair	Poor

Tayeh et al. (58) described a correlation between splitting tensile and slant shear strength, given in Fig. 5. Graybeal et al. (59) stated that the flexure strength test and the splitting cylinder test are related and showed higher bond strengths than the pull-off strength. The splitting tensile strength increased more for composite specimens with both limestone sand and glass powder applied to high-roughness surfaces than applied to drilled holes surfaces (38).

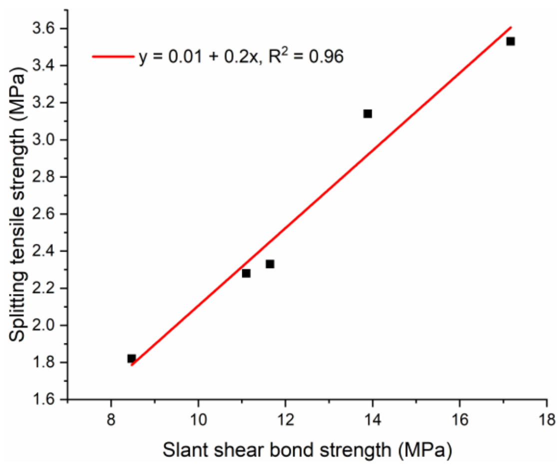

Fig. 5 Correlation of SST and STT (55)

3.2 Pure Shear Tests

Pure shear stress is assumed to act between the substrate and repair layers in the pure shear test. Various tests are available to determine interface shear strength, like torsion shear test (2), push through cube test (7), BSST (60–62), modified vertical shear test (57) (61), DST (63), and a mixed-mode of them.

3.2.1 Bi-Surface Shear Test

Momayez et al. developed BSST to determine substrate and overlay concrete bond strength (64). The test process is like the direct shear test (DST), but has a single shear plane and a single load arrangement. The primary advantage of this is that the loads applied uniformly to the composite concrete specimen through the steel plates. The test setup of the BSST has been shown in Fig. 3(a); however, this test method highly depends on the bonding agent, moisture content of the substrate surface, and the surface preparation method (42).

In this test, the specimen is prepared by filling two-third of the mould with existing concrete and the remaining one-third with new concrete. This test procedure is complicated due to the bonding material, substrate wetness, and surface preparation. The expected failure mode has been shown in Fig 8(a) with loading diagram for BSST. Kabay et al. (62) studied the effect of surface preparation on bond behaviour of composite with BSST and evaluated that smooth surfaces showed bond strength of nearly 2.9 MPa; whereas, the bond strength increased up to 134% for the rough surface. The use of a bond agent enhances the BSST bond strength but as compared to the shot blast treatment it is lower for the bond agent (40).

On the other hand, Lee et al. (65) used Ultra High Performance Concrete (UHPC) to overlay with Normal Strength Concrete (NSC) substrate and found that UHPC performed better in bonding due to high strength. This test also offers better results using mortar instead of concrete; but, there is a lack of correlations between the bond strength obtained by SST and other tests(66). Only Al-Rubaye et al. (60) found the relationship between bond strength, and it was reported that, by using SST and BSST, the Slant Shear Bond Strength (SSBS) was two to three times higher than the BSST strength. This is because the high compressive stresses that take place in a SST cause more friction and locking, which increases the shear failure load (14). To solve the problems of poor durability and low bearing capacity of existing concrete reinforcement, a BSST between reactive powder concrete (RPC) and ordinary concrete (OC) was conducted and it was found that RPC has better bonding performance with ordinary concrete. The bonding strength of the RPC and steel mesh-reinforced OC structure can be increased by 1.37–3.11 times compared with the OC-OC interface (67).

Hak-Chul et al.(68) investigated a relationship between BSST strength and Ca/Si ratio. The shear bond strength increases as the Ca/Si ratio at the interface increases. Because the Ca/Si ratio is an indirect measure of C-S-H and Calcium Hydroxide (CH), therefore an interface with high C-S-H contents is strong.

3.2.2 Modified Vertical Shear Test

The modified vertical shear test is helpful to determine the bond strength when reinforcement crosses the interface layer. It is also known as the L-shaped test or push-off test, and the test setup has been shown in Fig. 3(c). In this test, two L shape sections are used, and their inner interface is joined together by cross reinforcement, having a gap at both ends. The loading acting at the outer part is to be continued in the testing procedure until the interface fails in shear. The expected failures mode have been shown in Fig 8(c) with loading diagram for Modified vertical shear test. The push-off shear mainly depends on specimen size, bonding preparation, thickness, and shear reinforcement (29)(69). The use of shear reinforcement has a greater impact on the bond strength. It has been discovered that the interfacial bond strength decreases in geosynthetic fibre (70). A geosynthetic interlayer creates shear plane which allows the layers to debond more easily. However, by the use of fibers and grid reinforcement, shear and tensile bond strengths increased 331% and 456% respectively as compared to un-strengthened specimen (71). This higher bond strength was due to the conversion of interface shear failure into compressive failure due to, the fiber addition. Javidmehr et al. (72) used a grooving pattern at the interface to reduce shear reinforcement; due to the ultimate load increases as the roughness of the interface increases. The bond strength in this test is influenced by Compressive Strength (CS) rather than shear reinforcement. CS increases ultimate shear strength while decreasing cracks and residual strength (57). When the CS of the concrete was increased, the ultimate shear strength of the push-off specimens increased (61). Other than this, increasing adhesive thickness reduces maximum loads at the overlap side (73). Cattaneo et al. (72) discovered an analytical study of concrete bonding. The push-off test does not allow for the application of reversal cyclic loads.

3.2.3 Torsion Shear Test

It is like the POT; the only difference between this test and the POT is the torque application. The test setup has been shown in Fig. 3(f). A torsional moment (T) is applied at the top to determine bond strength, and T is increased until failure. Equation (1) shows the relationship between shear stress and the torsional moment (2). Dowan Kim and Sungho Mun (74) developed a torsion test for repairing of tack coat to understand its performance and define application standards.

$$Shear\ stress = \frac{16}{\pi} . \frac{T}{\emptyset^3} \tag{1}$$

Where ϕ is the core diameter.

3.2.3 Direct Shear Test

The DST is the most used test for determining bond shear strength. This test can be conducted using a single (75) or double shear plane (76). The specimen for this test is cast in a cube with half substrate concrete or half repair concrete, and the test setup has been shown in Fig. 3(j). This test applies opposite compressive forces to the composite specimen, each acting on a separate specimen region. Nowadays, the cube specimen is modified into a "butterfly" double wedge specimen with slits around the interface edge (63).

3.2.4 Guillotine Test

The guillotine test is a standard bond test that measures the substrate - overlay concrete bond strength. A compressive load is applied on the shear box, producing shear stress at the composite specimen's bond interface. This test is divided into three categories: the simple guillotine test, the double guillotine test, and the symmetric guillotine test, based on the loading or overlay material position and the systematic test setup have been shown in Fig. 3(h), Fig. 3(l), and Fig. 3(0) respectively. The expected failure mode have been shown in Fig 8(d) with loading diagram for Guillotine test.

Delatte et al. (77) suggested that the guillotine test is a laboratory test with limited use in situ due to the difficulty of loading conditions. In this test, bond strength is directly influenced by the overlay's mechanical and physical qualities (7).

3.2.5 Slant Shear Test

The SST is a standard bond test that was developed in 1976. Several standards, including BS EN12615 (78), ASTM C1042 (79), ASTM C881 (80), and ASTM C882 (81), are available to describe this test; various measures for the SST have been shown in Table 3 (44). In this test, cylinders or prismatic moulds are used to determine the bond strength by dividing the substrate-overlay concrete at various angles. The bond interface surface is prepared after casting the substrate concrete. Then, repair concrete over the substrate is cast after a specified time interval. In SST, the specimen is subjected to compressive, and shear stresses simultaneously. The expected failure mode has been shown in Fig 9(a) and Fig.9(b) with loading diagram for SST (compression) and SST (tensile), respectively. The bond strength is depending on various parameters like surface preparation, bonding agent, angle, and specimen size.

Table 3. Standards for SST(44)

Standard	Cross-section (mm)	Height (mm)	Angle with the vertical
ASTM C881	150 φ	300	30°
ASTM C882	75 φ	150	30°
NEP18-872	100×100	300	30°
BS EN12615	40×40	160	30°
BS EN12615	100×100	400	30°

Pedro Miguel Duarte Santos (82) and Harris et al. (83) found that bond strength mainly depends on surface preparation. According to Salim et al. (84), the bond strength of interface is affected by the substrate concrete's compressive and flexural strength, rather than the surface preparation. The minimum requirement of SSBS according to ACI 546-06, is 14-21 MPa at 28 d. Different specimens have been used to conduct SST based on different standards. The test setup has been shown in Fig.3(b) and Fig.3(e). The difference in SSBS by using different standards was observed by Diab et al.(44).

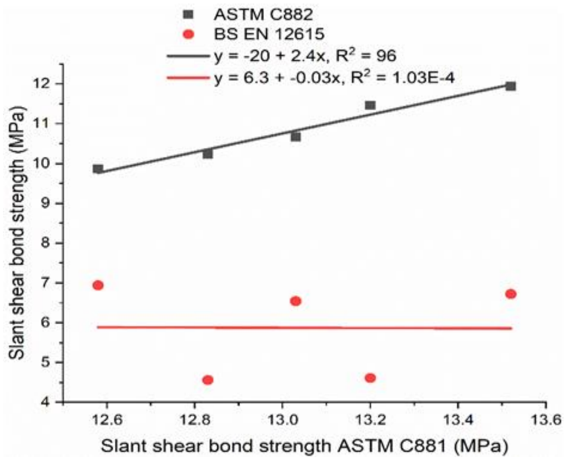

Fig. 6 Correlation of different standards for SST (44)

It has been noted that the coefficient of variation in results conducted by ASTM C881 was less than ASTM C882 and BS EN 12615. A higher value of SSBS was obtained when the test was conducted on cylindrical specimens than prism specimens. Fig. 6 compares different standards of SST and shows a strong correlation between both cylindrical specimens by ASTM C881 and ASTM C882. There was no correlation between prisms specimen of BS EN12615 and ASTM C881. Similarly, the SSBS and CS are related linearly; due to the use of PVA content compressive strength and SSBS increase in the same manner (85).

In addition to specimen size, angle with the vertical also influences the SSBS. For example, Harris et al. (83) showed substrate failure at 60° angle. However, adhesive failure was observed at 70° angle for the brushed interface between NSC and UHPC. In addition to repair and concrete strength, SST performance is dependent on bond and contact area. Increasing interface bond angle increases mixed failure risk. Zhang et al. (86) studied the different types of surface preparation on the substrate layer and found that the bond strength of the surface-milled and grooved composite increases with the curing; because, milling surface preparation removes laitance, pores, and other defects from the old concrete surface; that leads to better bond with overlay concrete. Similarly, the water jetting surface treatment increases bond strength up to 56% (87).

The surface angle orientation impacts the concrete mixture's bond strength (88). Wood (89) investigated how the slant angle of the interface layer influences the bond behaviour. The interface surface was inclined to vertical and varied from 10° to 50°. A slant angle of 40° or fewer causes adhesive failure, while a slant angle of more than 40° causes cohesive failure. According to Sun et al. (90), specimens with 45° inclination were unsuitable for SST due to greater compressive stress. Cohesive failure reduces interfacial bond strength. Numerous researchers (14)(40)(44)(45)(17)(82)(88,91–95), and ASTM C881 and ASTM C882 recommend 30° slant angle is best to determine the bond strength of substrate - overlay concrete. However, the widespread use of a single 30° slant angle is insufficient. A variety of slant angles should be studied to complete the interfacial behaviour gap (91)-(92). Gomaa et al. (96) used three slant angles, 20°, 25°, and 30°, to analyse the failure envelope of the specimen surfaces with the Mohr-Coulomb criterion. The failure occurred at a smaller angle because the interface joint was sliding along the interface layer.

3.2.6 Flexural Bond Test

Bending tests are used to determine the flexural strength of concrete. Based on the available literature, this test method is simple for evaluating the interface bonding [101]. In this test, a simple prismatic section is used, and the test setup has been shown in Fig. 3(c). Half of the prism is cast initially. Then, the overlay material is used in the remaining part. The stress distribution of this test is complex and depends on the contact plane's location and direction. In pure bending, only compressive and tensile stresses are important. However, in shear bending, both compressive and tensile stresses are important, along with shear stress. The expected failure mode have been shown in Fig 9(c) with loading diagram for flexural bond test. The bond strength determined by this test depends on the substrate concrete's strength, the surface preparation, and materials type. Aaleti et al. (97) describe the durability of tests with UHPC in bridge decks to enhance the service life of the decks. Numerous novel studies are conducted to verify the interface bonding behaviour. Some authors used a new frustum, split Hopkinson pressure bar (98), Double Sleeve Test (11) (99) to estimate the actual bond strength.

4. Failure Study

From the previous studies it can be stated that the bond between the substrate layer or overlay layer is a very crucial parameter that cannot be defined clearly; because, it depends on various factors like, subterete and overlay layer properties, selection of materials for both layer and other environmental factors. To determine the failure criteria of the composite section it is necessary to predict the numerous tests with the interface layer. Many types of tests available to determine the bonding behaviour based on the stress criteria has been shown in Fig. 7, Fig. 8 and Fig. 9 respectively. Three types of common failures that can occur based on material failure with stress are substrate failure, overlay failure and interface failure or mixed mode failure. The bond strength is directly influenced by the interface layer failure; but the substrate failure did not fulfil the demand of the direct measurement of bond strength. Similarly, the overlay failure shows that the overlay materials are not sufficient.

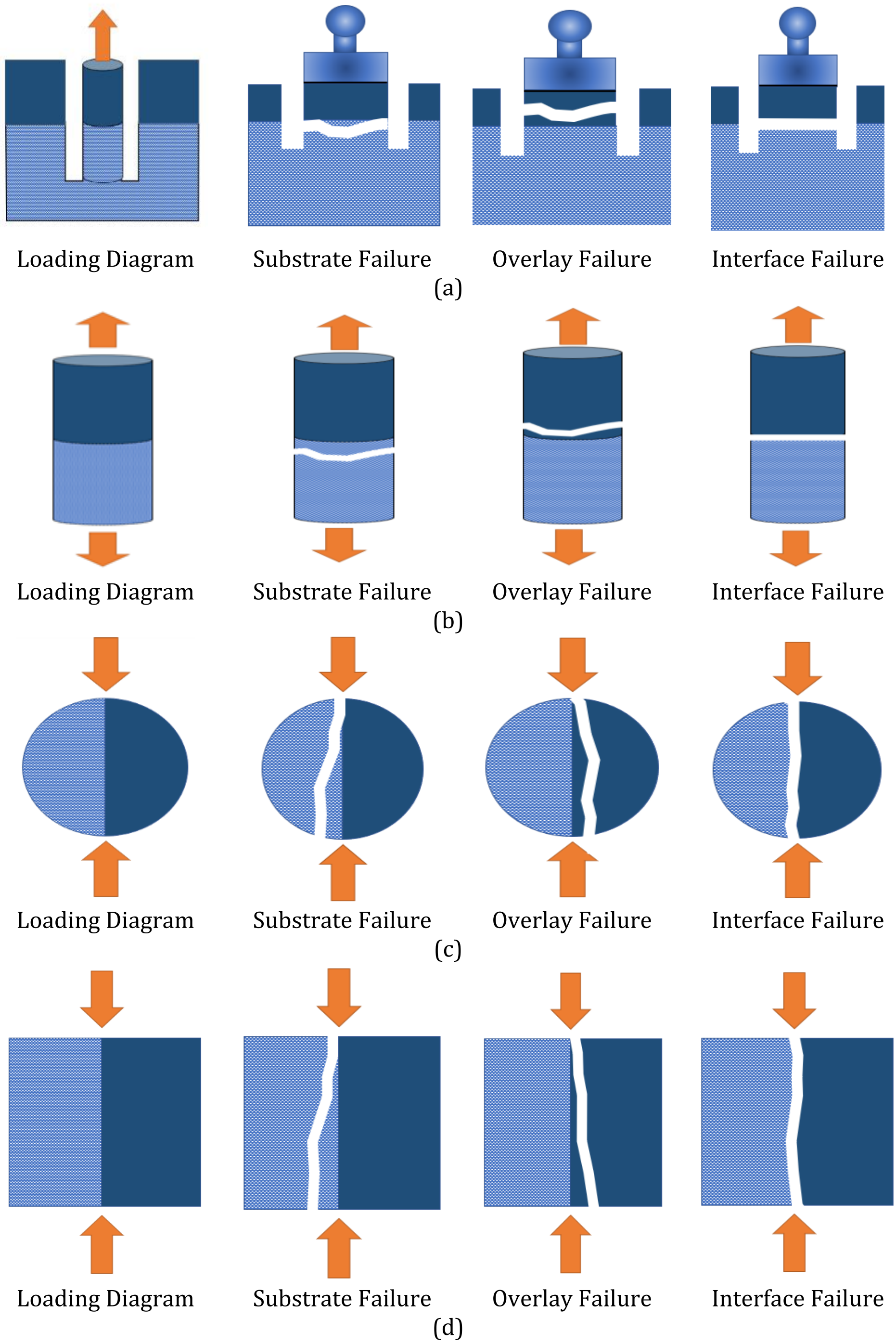

Fig 7. Loading diagram of pure tensile bond test with expected failure mode (a) Pull off test, (b) Direct tension test, (c) Splitting cylinder test and (d) Splitting prism test

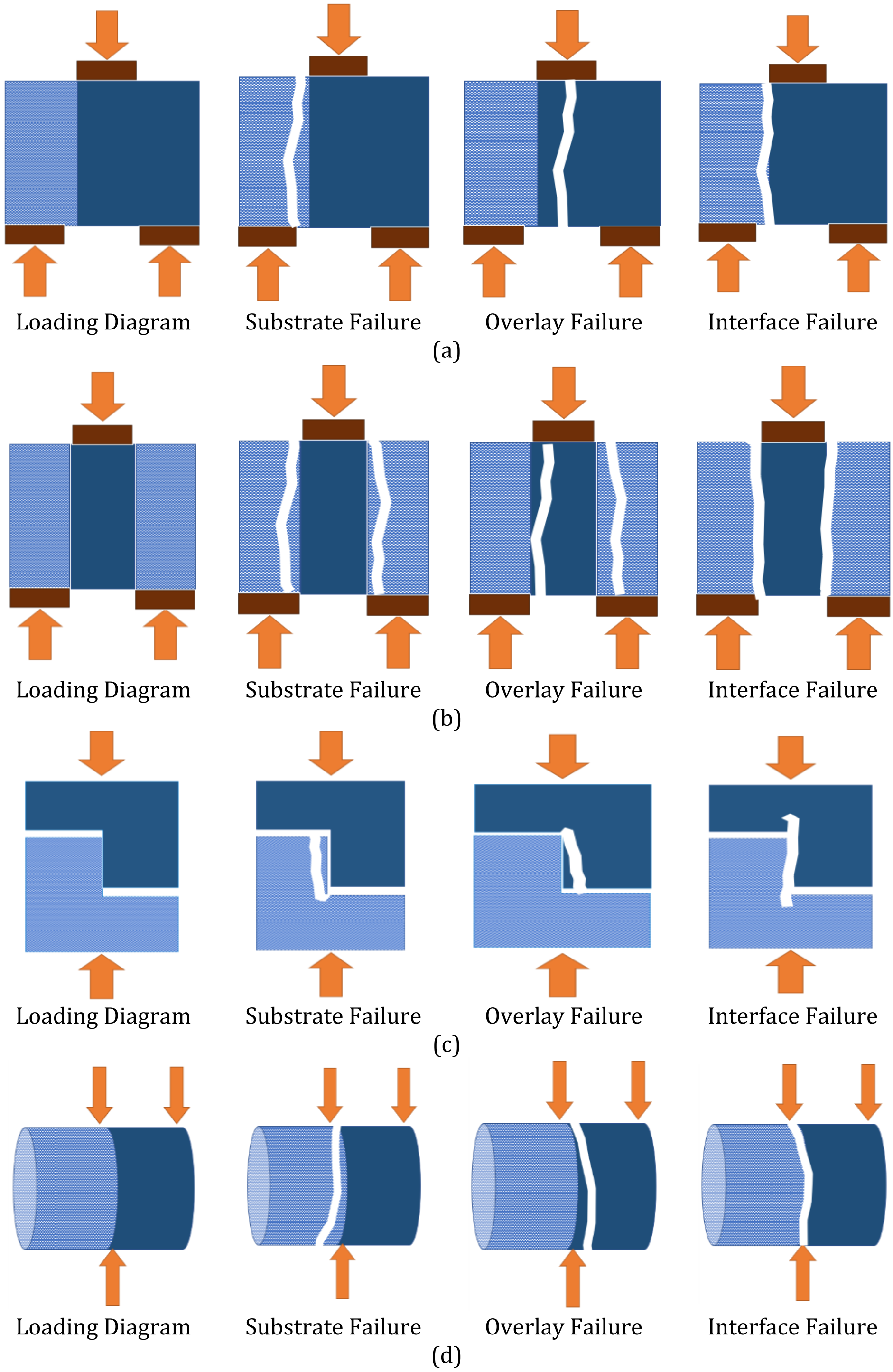

Fig 8. Loading diagram of pure compression bond test with expected failure mode (a) Bi surface shear test, (b) Push through cube test, (c) Modified vertical shear test and (d) Guillotine test

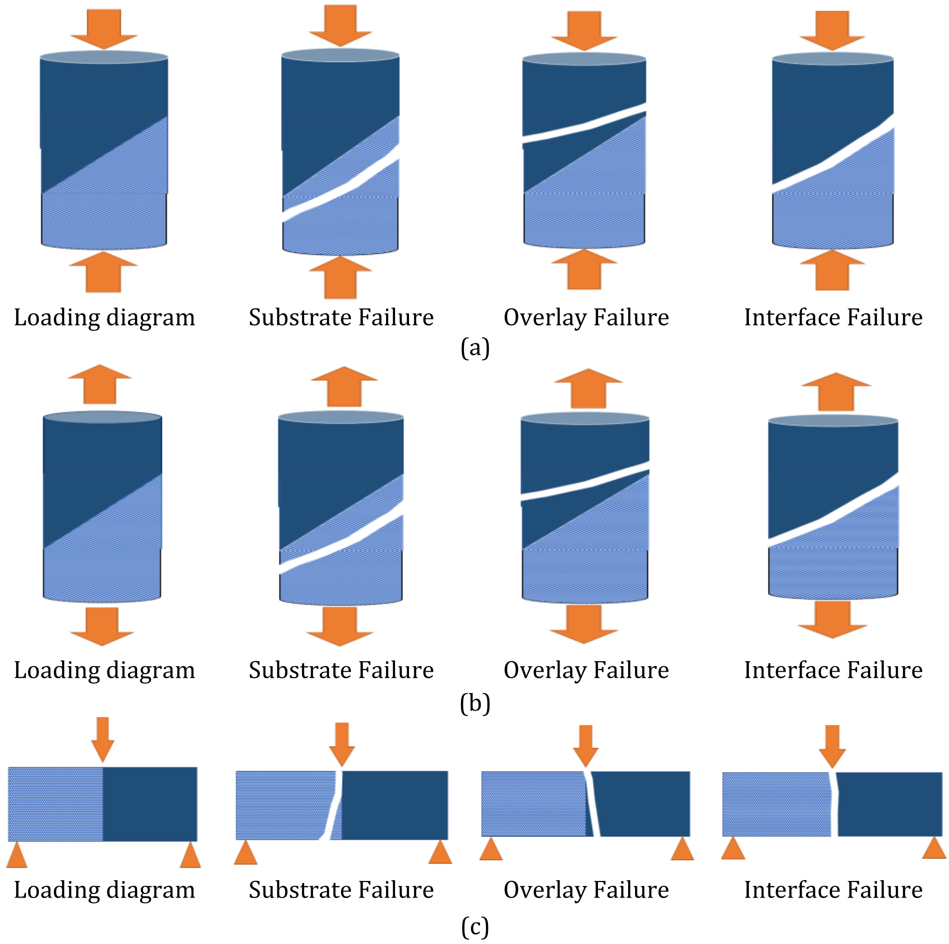

Fig 9. Loading diagram of mixed mode of stress bond test with expected failure mode (a) SST (compression), (b) SST (Tensile) and (c) Three- point bending test

Other than this, partial failure or mixed mode failure can occur due to the stress applied to it (83). Although each of these failure types give useful information regarding the performance of the system, only the interface failure mode accurately defines the bond. When Epoxy is used at the interface layer, a thin layer was formed over the substrate which leads to substrate failure (30).

Sun et al. (90) determined the failure pattern with the use of UHPC as an overlay on NSC by SST and STT, it was observed that most of the specimens failed in the substrate or partial interface failure. Similarly, Based on the test specimen and failure characteristics under various experimental conditions, six types of interfacial shear failure were recorded and most of the failures occurred partial failure; due to the UHPC surface attached to the partial thin layer of NSC (100). The interfacial failure modes were determined with double-sided DST and most specimens failed partially interface with NSC or completely NSC, and a few failed within the interface (49). Liao et al. (101) found the bond behavior with mortar and the failure was characterized into two patterns, uncracked or cracked failure. From the failure mode, it is clear that mortar thickness influenced the failure behavior. Ganesh et al. (30) expected the bond behavior with model analysis and found that the maximum difference in the experimental bond strength and model bond strength was nearly 12%. It is critical to understand that the result of a specimen that did not fail at the bonding interface (for example, a pull-off test that failed in the substrate concrete) will show interface bond stress at specimen failure, not interface bond strength (59).

Rather than the layer failure the full failure is subdivided into adhesive failure and cohesive failure based on the loading process. Numerous authors (14)(12)(17)(28)(102)(103) have researched both adhesive and cohesive parameters to avoid failure. Failure of an adhesive occurs when the plane of failure is parallel to the contact surface. When the material compressive strength exceeded, cohesion failure occurred (92). the basic parameter defined by Naderi et al. (104) that affects the bond strength and mode of failure are described as:

- Substrate soundness- Many authors (77)(105)(106) focused on how this parameter affects the strength and mode of failure, and it is noticed that increasing roughness can also lead to a change in failure mode, from the adhesive mode to the cohesive mode.
- Shrinkage of the new layer- According to (82) the slant-shear strength increases as the difference in age between the two different concretes increases (107).
- Interface angle- it also influences the failure mode. It can be stated that adhesive failure cannot be prevented only by adequately defining the interface angle.
- According to Austin et al. (108), who investigated the SST failure modes, the normal/shear stress ratio is controlled by the interface angle. It is suggested to test different interface angles, for each surface treatment, to obtain a bond failure envelope. Zambas (109) examined the effects of the slant angle on the bond behavior of new-to-old concrete interfaces. The inclination angle of the interface from vertical was in the range of 10° to 50°. Test results showed that when the slant angle is not greater than 40°, failure occurs along the interface, which is referred to as an adhesive failure, and that when the slant angle exceeds 40°, the weakest concrete is crushed, which is regarded as a cohesive failure.

5. Conclusion

- Past studies have covered the effect of various factors on interface layer bonding, workability, surface roughness, bonding agent, surface moisture condition, overlay materials strength, age of concrete, specimen size, micro-cracking, shrinkage of concrete, cohesion in the substrate concrete, aggregate interlock, and other time-dependent factors. Most past studies have focused on testing the efficiency of different test setups to determine a perfect bond. The roughness substrate surface improves binding strength over a smooth surface.
- Due to the simplicity most of the researcher used SST, STT followed by POT and avoided the mixed mode of test due to complexity.
- POT test showed better results for bond strength but its complexity restricts its use. The main disadvantage of this test is that the specimen partly destroyed during testing and the complexity of bonding.
- Bond strength by the SST shows higher bond strength than BSST and SST is chiefly used to test the bond strength of substrate-overlay concrete because of the simplicity of the test.
- The interference failure is observed in most of the cases due to, the lack of EBA.
- The above results are based on the various research observations; further research is required to explore suitable methods, materials and surface techniques.
- The BSST is more suitable to find bond strength; The test procedure is simple and utilizes the same specimen as the BSST and the loading procedure is simple like the split cylinder test.

- By using SST and BSST, the SSBS was two to three times higher than the BSST strength. This is because the high compressive stresses that take place in a SST cause more friction and locking, which increases the shear failure load.
- The guillotine test is a laboratory test with limited use due to the difficulty of loading conditions. In this test, bond strength is directly influenced by the overlay's mechanical and physical properties.
- When Epoxy is used at the interface layer, a thin layer was formed over the substrate which leads to substrate failure in most cases.

Conflicts of Interest

"The authors declare no conflict of interest."

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