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A Comprehensive Review on Abrasion Resistance of Concrete

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Abstract: Increase in vehicular traffic and changing environmental; will reduce the service life of concrete surfaces. Repair and maintenance of concrete pavement and floors is a routine practice in India to enhance the serviceability. Abrasion is contributing in lowering the service age of concrete. Many structures such as dams, canals, industrial floors and roads are required to have sufficient abrasion resistance. Abrasion resistance is a property of harden concrete surface to be worn away by abrasive forces. Highly abrasion resistance concrete surfaces are preferred in industry floor and in construction of roads. Aggregates play an important role in strength characteristics of concrete; strength has a decisive influence on abrasion resistance of concrete. This paper presents an overview of some of the research published regarding abrasion testing and effect of concrete properties and ingredients of concrete on abrasion resistance. Studies show that this is promising future for the abrasion resistance of a concrete used in road pavement, industrial floors, dams etc. to assess the serviceability. It was notices from literature that abrasion properties are varying with aggregate type, compressive strength, cement content, W/c ratio, curing and show drastic changes when concrete added with silica fumes, fly ash, fibers and latex. Age of the concrete and type of loading for which concrete surface is exposed play vital role in abrasion. This study culminates to explore abrasion resistance property on assorted mix design, high density concrete and age of concrete.

Keywords: Abrasion; serviceability; high density concrete; age of concrete.

1. Introduction

Concrete is major construction material used in all over parts of world. Concrete serves as pavements, air run ways, buildings, hydraulic structures, industrial floors etc. Concrete structures are resisting several natural and artificial calamities. Concrete surfaces exposed to environment are undergoes temperature changes, sulphate attack, freezing and thawing, climatic changes etc. Use of concrete in construction of pavement, industrial floors leads to rubbing, scraping, skidding, sliding of impact loads due to movement on surfaces. These actions result in deterioration of concrete surfaces [1, 2]. Fracture of surface leads to reduction of concrete thickness, makes smoother surface and increase dust on concrete surface which weaken concrete and make in inconvenient to use [3]. In spite of above preseason, scant attention has been paid to hardness, toughness and abrasion resistance of concrete.

Abrasion resistance is an ability of concrete surface against abrasive actions (e. g. rubbing, rolling, sliding, friction forces and impact forces) [1, 4]. Abrasion resistance is depending upon application of concrete surfaces and service conditions which is conditional to classify abrasion resistance as shown in Table 1 [5].

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Abrasion of concrete surface depends upon its compressive strength, water-cement ratio, aggregate type, hardener (topping), surface finish and testing procedure [1, 4, 6]. This paper deliberates the study of abrasion resistance; it's testing procedures to assess abrasion resistance, effect of ingredients on abrasion resistance of concrete and concluded in essence of possible ways of assessment, abrasion resistance of special concrete.

Table 1. Classification of abrasion resistance.

Class	Application of surface	Service condition
AR3 (Moderate Abrasion)	Road pavement, light duty industrial and commercial etc.	Surfaces exposed to rubber tyre traffic
AR2 (High Abrasion)	Medium duty industries and commercials, warehouses etc.	Steel and hard plastic wheel traffic, high loaded rubber tyre traffic
AR1 (Very high Abrasion)	Heavy duty industries, workshops and warehouses etc.	Impacted steel and hard plastic wheel traffic.
Special (Sever Abrasion)	Very heavy duty engineering workshops and very intensively used warehouses, etc.	Steel or hard plastic-wheeled traffic or scoring by dragged metal objects

2. Abrasion Testing Procedures

Tests to determine abrasion resistance are published in various countries as per the use of concrete surfaces. Assessment of abrasion resistance of concrete is attempted by varying load conditions though different tests. American Society for Testing and Materials (ASTM), Indian Standards (IS) and many other codes put out standard test of abrasion [7–13].

2.1 ASTM Testing Procedures

ASTM standards give following standards for testing [13]

- ASTM C 418- 'Test method for abrasion resistance of concrete by sand blasting'
- ASTM C 944-'Test method for abrasion resistance of concrete or mortar surfaces by the rotating-cutter method'
- ASTM C 779/ C 779M- 'Test method for abrasion resistance of horizontal concrete surfaces'
- ASTM C 1138-' Test method for abrasion resistance of concrete – Underwater Method'
- ASTM C 1747/C1747M-13- 'Standard test method for determining potential resistance to degradation of pervious concrete by impact and abrasion'
- ASTM C1803-15- 'Standard guide for abrasion resistance of mortar surfaces using a rotary platform abraser'

2.1.1. ASTM C 418: [8, 13]

This test procedure is working on principle that to abrade the surface by sand blasting and observed the abrasion of surface under controlled conditions. The blast cabinet integrated part of method which is holding specimen, injector type blast gun with high velocity air jet. Worn out of surface by waterborne particles and abrasive under traffic is observed. Abrasion can be observed under varying pressure, abrasive charge, distance between nozzle and surface, type of surfaces etc. Abrasion measured in terms of coefficient of abrasion which is volume of surface abraded to area of surface abraded.

2.1.2. ASTM C 944: [10, 13]

The rotary wheels are in contact with concrete or mortar surface to check the abrasion of concrete. Concrete surfaces are specially fabricated or core from the element. This method specifically used for quality control of highway and bridge concrete subject to traffic conditions. Difficulties in variations of load are overcome by applying constant load of 98 N on cutter through spindle.

2.1.3. ASTM C 1138: [9, 13]

Determining the abrasion resistance of concrete underwater, abrasive force is applied by waterborne particles. This test qualitatively simulates the behavior of concrete surface against the water impact, swirling water, water scouring. Concrete specimen underwater with rotary paddle and abrasive charge/balls produce abrasive actions on surface. Volume loss in this test is abrasion.

2.1.4. ASTM C779/C779M: [7, 13]

Three test procedures are published to simulate an abrasion condition which evaluates the abrasion resistance of concrete.

a. Procedure A- Revolving disc machine:
   This test procedure introduces the rubbing, grinding abrasive forces by revolving disc and abrasive powder. Three revolving discs of 60 mm which are rotating at 12 revolutions per minute on circular path and individual disc is rotating with 280 revolutions per minute to its own axis. Silica carbide is used as abrasive powder to feed during test. Test period is 30 minutes but special conditions may extend up to 60 minutes. Depth of abraded surface after test period is recorded and interpreted as abrasion resistance of concrete.
b. Procedure B- Dressing Wheel Machine:
   Similar procedure is followed as procedure B, revolving discs are replaced by dressing wheels. Dressing wheels are producing rolling, pounding and cutting action of steel wheel. Three set of seven dressing wheels are exerting abrasive force without abrasive charge by revolving 56 revolutions per minute at vertical motor drive spider arrangement. Test is completed after 30 minutes of dressing wheel run on surface (may extended up to 60 minutes as per the recommendation to observe the severe abrasion). Test on three test surfaces is conducted to evaluate the abrasion resistance. Dressing wheel abrade double depth than the revolving disc.

c. Procedure C- The Ball Bearing Machine:

Abrasive actions are produced by rapidly rotating ball bearing under load on wet concrete surface. Water is used to remove loose particles from surface, allows contact of ball bearing with surface. Series of eight ball bearings are rotating under load at the speed of 1000 revolutions per minute. Abrasion reading are taken after every 50 revolutions with depth measuring instrument, abrasion depth measures for total 1200 revolutions or until maximum depth reached up to 3.0 mm.

2.1.5. ASTM C 1747/C1747M [12]

This test method determines comparative resistance to degradation of pervious concrete of different mixes when subjected to combine action of impact and abrasion. Degradation of concrete is measures by loss in mass after test. This test is not intended for qualification of mixtures and limiting maximum size of coarse aggregate up to 25 mm only. Raveling is caused in pervious concrete which is related to dislodgement of aggregates and affecting to wear of surface. Cylindrical mould with 200 mm height and 100 mm diameter is used for sample/ specimen casting. Three samples are suggested to produce a single test result. Measure the density of concrete at initialization of test, fill 100 mm concrete in the mould which is followed by compaction (i. e. ten times free fall of mould from 25 mm height and Marshall Hammer). Note the height of compaction after each blow of compaction. All specimen used should be compacted in same manner. Moisture loss during curing can be avoided by fitting cap to the mould. Initial curing is done up to 48 hours at 16℃ to 27℃ without disturbing sample in first 24 hours. Further curing is done at 23℃ for 7 days without removing assembly of mould and cap. Abrasive and impact are acted on cured specimen through Los Angeles machine without charge of steel spheres. Rotate machine for 500 revolutions at 30 to 33 revolutions per minute. Calculate the percentage mass loss after testing, carry sieve analysis of abraded material to note the material retaining on 25 mm sieve. With above mentioned procedure, comparison of pervious concrete mixes on the basis of mass loss, density, void content of mixture is possible which gives the potential abrasion resistance of particular mix.

2.1.6. ASTM C1803-15 [11]

Relative abrasion resistance by mass loss, wear index or volume loss of mortar sample is evaluated by this method when sample subjected to rolling and rubbing actions produced by rotary platform abraser. Vitrified or resilient based wheels are adjusted on pivoted arm of rotary abraser. Wheels are of size 12.7 mm thick and external diameter 51.9 mm, are acting on mortar specimen of 100 mm square and thickness not greater than 13 mm as shown in Figure 1. Pivoted arms are pinned with 1000 grams of weights before procedure start. Mortar specimen undergoes the abrasive actions in 200 rotations for normal surface and 1000 rotations for more robust surface. Vacuum cleaning is done by vacuum pick up nozzle to a distance of 3 mm above the specimen. Cleaning by stiff brittle brush is suggested after every 50 cycles. Wear of specimen after every 50 cycles which give linearity in testing procedures.

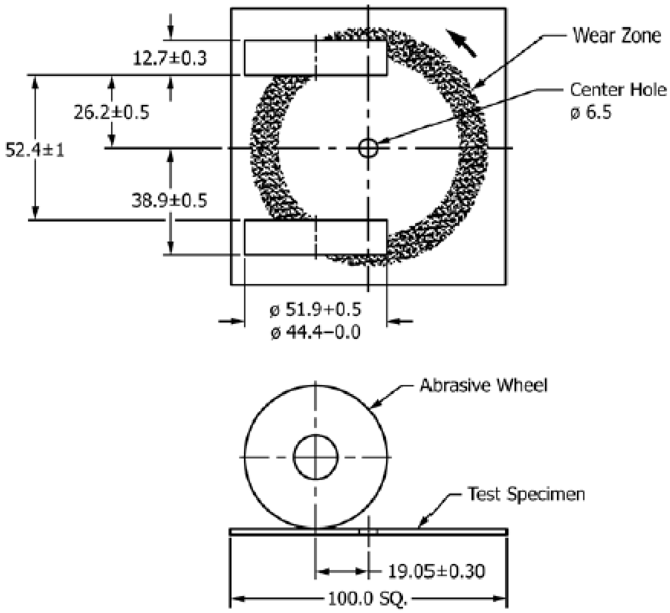

Figure 1. Arrangement of abrasive wheel and specimen on turntable.

Aesthetic and calculated evaluation is carried for the specimen. Aesthetic evaluation can be done in terms of apparel changes, which may include the change of gloss, colour loss, loss in coating. Instead of above generic evaluation this standard suggest following evaluation practices;

a. Mass Loss (WL)
   $WL= W_0-W_1$
   Where, WL= Mass loss during test in milligrams,
   W_0= Mass of test specimen before test in milligrams,
   W_1= Mass of test specimen after test in milligrams.
b. Wear Index (WI)
   Wear index is loss in mass due to abrasion in milligrams per 1000 cycles of abrasion testing machine.
   $WI= ((W_0-W_1)*1000)/C$
   Where, WI = Wear Index,
   W_0= Mass of test specimen before test in milligrams,
   W_1= Mass of test specimen after test in milligrams,
   C= number of cycles of abrasion recorded.
c. Volume loss
   Volume loss used mostly to compare specimens with different densities. Volume loss is calculated;
   Volume loss= (Wear Index)/ (Density of specimen)

This guide used to quantify the abrasion resistance of mortar surfaces and acceptance of mortar surface. This guide also used to evaluate the performance of hammer, surface densifier applied on surface. Results of this test may correlate with in-place performance and performance of alternative materials.

2.2 Indian Standards Procedures

Indian standard for abrasion resistance of concrete can be examined by

2.2.1 IS: 1237 –1980 (Reaffirmed 1996) 'Specification for Cement Concrete Flooring Tiles' [14]

This standard published a standard test method for determination of resistance of wear with abrasion testing machine. Concrete tiles specimen of 70.6 X 70.6 mm loaded with 300 N and surface in contact with grinding disc at a speed of 30 revolutions per minute in presence of abrasive powder. Wear depth is observed at five locations on surface of specimen, rotating specimen by 90^o after every 22 revolutions. Test completed and set of observation is ready for analysis after 220 revolutions on one surface. Average loss in thickness in mm is finding by

$$t = [(W_1 - W_2) V_1] / (W_1 X A) \quad (1)$$

Where W_1 is initial mass of specimen, W_2 is final mass of specimen, V_1 is initial volume of specimen and A is area of specimen. This code provides the maximum permissible wear depth for general purpose tiles is 4 mm, where for heavy duty permissible wear depth is 2.5 mm.

IS 1237 is limiting test for definite thickness of concrete specimen (i. e. tiles). The application of this test is not mentioned for concrete pavement or for high depth concrete members.

2.2.2 IS: 9284–1979 (Reaffirmed 2002) 'Method of Test for Abrasion Resistance of Concrete' [15]

This code describes the method of assessing the relative wear resistance of concrete surfaces by finding abrasion loss subjected to abrasive charge. This test is suitable to assess abrasion for roads, air fields, industrial floors, railway platforms, dock yards, footpaths etc.

Concrete cube specimen of 100 mm is subjected to the impingement of air driven silica sand in pneumatic sand blast cabinet. Wooden cabinet with tightly closed door is maintaining the separate system as shown in Figure 2. Concrete surface is exerted abrasive force by 4000 grams impingement at a pressure of 0.14 N/mm^2 which results in the loss of mass. Recorded loss of mass is expressing in percentage loss which is abrasion resistance for that particulars concrete surface.

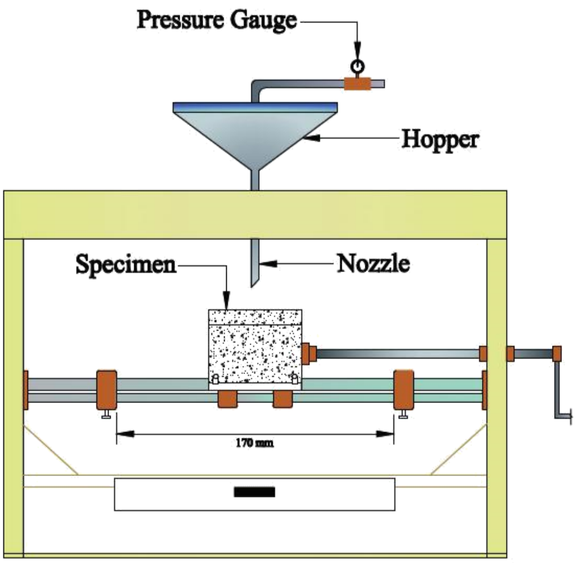

Figure 2. Arrangement made for testing abrasion in IS 9284.

IS 9284 provides the maximum values of abrasion loss in percentage as applications of concrete surfaces as given in Table 2;

Table 2. Maximum abrasion loss (IS 9284).

Sr. No.	Surface Applications	Maximum values of Abrasion Loss, Percentage Loss
1	Concrete Pavement	
	With mixed traffic including iron-tyred traffic	0.16
	With pneumatic tyres only	0.24
2	Factory floors	0.16
3	Dockyards	0.16
4	Railway platforms	0.24
5	Footpaths	0.40

This code recommended for normal weight concrete with density 24-26 kN/m^3 but not commented for high density concrete. This test procedure is laboratory method, field applications for road pavement, direct test on horizontal concrete surfaces is to be concentrated.

3. Effect of Concrete Constituent on Abrasion Resistance

Abrasion resistance property was observed by various parameters by researchers with varying conditions. Summary of abrasion resistance with respect to parameter is discussed.

3.1 Cement Content and Compressive Strength

Reference [16] focus on effect of variation in cement content on compressive strength and abrasion, variation in cement content from 200 kg/m^3 to 250 kg/m^3 shows rapid increasing in strength and up to 300 kg/m^3, slightly increase in strength. In strength point of view, for a given W/C ratio after optimum cement content the increase in cement content is unnecessary. Abrasion losses are decreasing with increasing cement content. Abrasion increases with increase in W/C ratio for same cement content. Abrasion is decreasing as increase in the compressive strength and density. Concrete prepared for bridge deck with silica fume and slag had superior abrasion resistance related to controlled mix as well as to those with higher silica fume content. Durability characteristics do not affected by aggregate type. Curing methodology is significant parameter to improve abrasion resistance [17].

Reference [18] examines abrasion by ASTM C779 procedure C & ASTM 1138, the test duration is affecting on abrasion in regardless of test surface and method used. Mechanical abrasion fractured upper layer and touches to the aggregate, aggregate properties are affecting to abrasion. Use of granite as aggregate improves the abrasion resistance properties over a conventional used aggregate concrete. Test conducted after 28 days shows the significant improvement than the earlier age. Increase in the cement content and addition of hematite material as an aggregate in replacement of lime stone and lead to increase the compressive strength. Combination of both offers great resistance to wear. Cement – hematite aggregate bond strength has been increased up to remarkable limit which resulted into wear resistance [19]. Compressive strength is most important factor in abrasion resistance and followed by W/C ratio, workability, air-entrainment, type of finish and curing conditions. Lower W/C ratio concrete provides high strength & high dense concrete which resist wearing. Surface attribution is main factor which affects abrasion test [20].

Abrasion test conducted on crumped rubber concrete shows better results when 10% and 25% crumped rubber replaced to aggregate. Extra abrasion resistance is noted by 40% to 60% replacement but reduction in compressive strength is noted [21]. Abrasion resistance is a property which is depends upon area, if fraction and properties of individual exposed phases. Modified Reuss model describe that abrasion resistance is non-linear function of individual phases [22]. A rubberized concrete shows the better resistance than the controlled mixes when mixes up to 20% at same W/C ratio. Water-cement ratio of 0.5 shows similar abrasion as to 0.4. Addition of rubber is significant in abrasion resistance except 7.5% inclusion of rubber in concrete. Rubber particles at the top of surfaces are acting as brush during testing and resulted in comparatively less abrasion [23]. Sound, hard aggregates show the better result in abrasion testing. High strength and low water cement ratio is critical for the concrete to resist stresses imposed by abrasion. Moist curing and finishing is adopted for significant having impression on abrasion resistance irrespective of constitutions of concrete [24]. Effectiveness of factor on wear resistance is varying with test procedure; selection of test procedure in terms of wearing environment is most important factor. Wearing resistance is rapidly increased with compressive strength up to 65 MPa [25]. Use of silica fume is increasing the dense hydrated calcium silicate to provide more refined pore system which resulted in improvement in abrasion resistance by 32-42%. Combination of silica fume and steel fibers provide 8-15% improvement in abrasion resistance. Addition of rock wool also enhances the abrasion resistance. Bond strength of cement paste and fibers used in concrete is effective parameter which is affecting on abrasion resistance [26]. Coefficient of abrasion loss observed is 14.7% to 58.5%, the best abrasion resistance recorded by specimens who are especially casted for abrasion resistance. The test method C944-80 may use to predict the serviceability of paving block [27].

3.2 Fly Ash

Abrasion study concentrated on high volume fly ash concrete, concrete constituting OPC, Class F fly ash and super plasticizers are producing high strength concrete specimen. High volume fly ash (70%) shows the slightly high abrasion resistance than controlled concrete and 50% fly ash containing concrete. Additional hydration reaction produces C-S-H which fills the pours and provides cohesion to ingredients. Workmanship is vital factor in abrasion where super plasticizers are playing neutral role in abrasion resistance [3]. The mixtures of fly ash replacing to the fine aggregate from 10% to 40% is tested by IS 1237-1920. Depth of wear is influenced by wearing (testing) time. Wear depth is increased as increased in the fly ash percentage at 28 days, 91days and 365 days [28]. Abrasion depths decrease while the curing time elapses. Concrete specimen approaches an ultimate abrasion resistance in 6 to 9 months. Highest pozzolonic material ratio of 25% - 30% by mass is a boundary of abrasion resistance [29]. Reference [30], the compressive strength tested on 1, 3, 7, 28, 91 and 365 days age with various fly ash mixes up to 70% (replacement to cement) is high at 30% fly ash mixture at 28 days. This investigation shows that abrasion resistance of concrete mixture is increased up to 30% by using fly ash mixture is similar to no fly ash mixture. Beyond 30%, it decreases slightly and at 70% of fly ash mixture shows poor abrasion resistance.

3.3 Latex

Reference [2] investigated abrasion resistance on mortar with latex carbon fibers and silica fumes. Specimen casted with OPC and water reducing agent had tested by C944-90. Addition of latex shows limited improvement in abrasion resistance but further improvement shown by adding silica fume. Combination of latex and carbon fiber improved abrasion resistance than silica fume & latex. Self-compacting concrete with silica fume is more abrasion resistance than vibrated traditional concrete and self-compacting concrete with combination fly ash and silica fume. Abrasion resistance is dependent parameter of compressive strength and modulus of elasticity, does not depend upon tensile strength of concrete. Relation developed between wear loss and compressive strength is best fit curve in form of $y=ab^{-x}$ with R^2 value of 0.94, similar form of equation followed to modulus of elasticity where R^2 value of 0.97 [31]. Pervious concrete specimens with latex are showing more abrasion resistance than fibers. Improvement in abrasion resistance is caused due to intermingled and interpenetrated matrix structure formed by latex and cement hydration products [32]. Nano SiO_2 is more efficient in abrasion resistance than super fine silica, study shows increment ratio of abrasive strength for Nano SiO_2, super fine silica and rubber powder at 28 days is 1.50, 1.33 and 1.71 respectively. Although increment ratio for super silica and rubber powder is comparatively high but which is not in accordance with the influence on compressive strength [33]. Use of 10% and 20% quartz powder in concrete, increases the abrasion resistance by 13% and 20% respectively. Most abrasion resistance concrete surfaces are least porous and absorptive [34]. Bonding between rubber aggregate and cement is not influencing to abrasion but to compressive strength. The statistical analysis reveals that addition of rubber in concrete is having positive effect on abrasion resistance. Abrasive depth was observed for controlled concrete is 1.41 mm where all mixes with rubber were showing depth less than 1.41 mm [35].

3.4 Fibers

Percentage improvement achieved by steel fiber concrete in abrasion resistance when compared to plain concrete. Abrasion resistance improved from 8% to 79%, testing specimen casted at constant fiber dosage at 0.51% by volume. Fiber dosage were varied from 0.51%, 1%, 2% and 3% by volume which shows that up to certain dosages compressive strength is increased, dropped down after 1% of fiber dosages because of workability. Effective abrasion resistance is at 0.51% fiber addition by volume in concrete [36]. Use of hematite as aggregate in plain concrete significantly increase in compressive strength were observed, addition 10% of hematite decreasing the loss of wear by 50% which happened by presence of Fe_2O_3 . The relation between compressive strength and wear loss is stated by $y = 7E + 15\ x^{-8.604}$ where R^2 is 0.9788 when concrete with hematite [37]. Cement replacement at 30% by fly ash shows optimum abrasion resistance than any other mixes. Inclusion of fiber acts as crack arrester in concrete which help in abrasion resistance [38]. Increase in the compressive strength in addition of steel fibers at 0.55 water-binder ratio, but great loss in wear had observed. Addition of steel fiber at higher water-binder ratio is not suitable for abrasion resistance [39]. Reactive powder used in concrete with varying water-cement ratio from 0.18 to 0.26 shows percentage loss in wear are 1.84% to 2.4%, addition of fibers in similar condition abrasion loss is improve from 1.52% to 1.72%. Reactive powder with higher water-cement ratio produced more porous concrete. Combination of reactive powder and steel fibers had produced more dense and abrasive resistance concrete [40]. Abrasion resistance study in natural environment for 900 days is effective than correlating it at 90 days. High abrasion resistance achieved in addition of granular rubber further enhancement in study with respect to polymer binder, binding-in technology and durability should be concerned [17, 41].

4. Workability and Abrasion Resistance

There is no direct correlation between the field performance and workability and abrasion resistance of concrete [42, 12]. This study protracted with discussion on mixing, placing, compaction and finishing phenomenon and abrasion resistance.

Concrete containing less than 6 percent air entrainment has the same abrasion resistance as normal concrete. Progressive decrease in abrasion resistance is observed with further increase in the air content. Abrasion resistance is markedly low when air entrainment is about 10 percent. Air spherical bubbles (5 microns to 80 microns) are intentionally incorporated in concrete to increase workability. Concrete with air entrained having 7.5 cm slump is superior to that non-air entrained concrete having 12.5 cm slump [43]. Better mixing of concrete produces more homogeneous concrete which gives better abrasion resistance.

Placing and compaction lead to dislodgement of aggregates which cannot withstand to abrasive forces. Angular shape aggregates are preferred for uniformly firmed in the concrete matrix, wearing out of the surface due to abrasive force will be uniform without pitting. Placing of homogeneous un-segregated concrete exhibits better abrasion resistance [43]. Compressive strength of concrete possesses more strength when it compacted with vibrator than compacted by rod and concrete without compaction. This happens when air entrapped is released while compaction, formation of good matrix and surface of concrete with paste of fine aggregate is enough sufficient to withstand against abrasive forces [42].

Cement paste must be contained by fine aggregates and matrix must be contained coarse aggregates, such uniform mix, devoid of excess paste on surface which upshot almost no shrinkage and withstand against abrasion. The stiffness at the time of trowelling, trowelling time, method of trowelling will all become important to improve the abrasion resistance of concrete surfaces [42].

5. Near Surface Properties and Abrasion

Concrete cover is permeable and weakest part of concrete due to its structure against external attack than the internal part of concrete. The porosity noted higher at surface than the internal part. Supplementary to cemetitious material like metakaolin and silica fumes formed a dense cement matrix at surface which contained less pore and less permeable surface structure. Low sorptivity is observed below 0.25 $ml/m^2/s$ due to use of supplementary to cement. Surface microstructural properties increased by addition of metakaolin and silica fume, study also recommended these materials for greater abrasion resistance [44]. This study intended to correlate the surface abrasion with pore size, pore distribution and surface hardness for hand finishing, power finishing and repeated power finishing. Intruded pore volume for repeated power finishing was less; ranging from $5.2x10^2$(ml/g) to $5.9x10^2$ (ml/g) at top surface and $8.2x10^2$ (ml/g) to $9.9x10^2$ (ml/g) at middle portion of concrete. Abrasion depth verses total pore volume plotted as shown in Figure 3, straight line fitted for all observed data with highly significant correlation coefficient of 0.97. Concrete mixes experimented in this study was tending more abrasion depth for increased total pore depth [45].

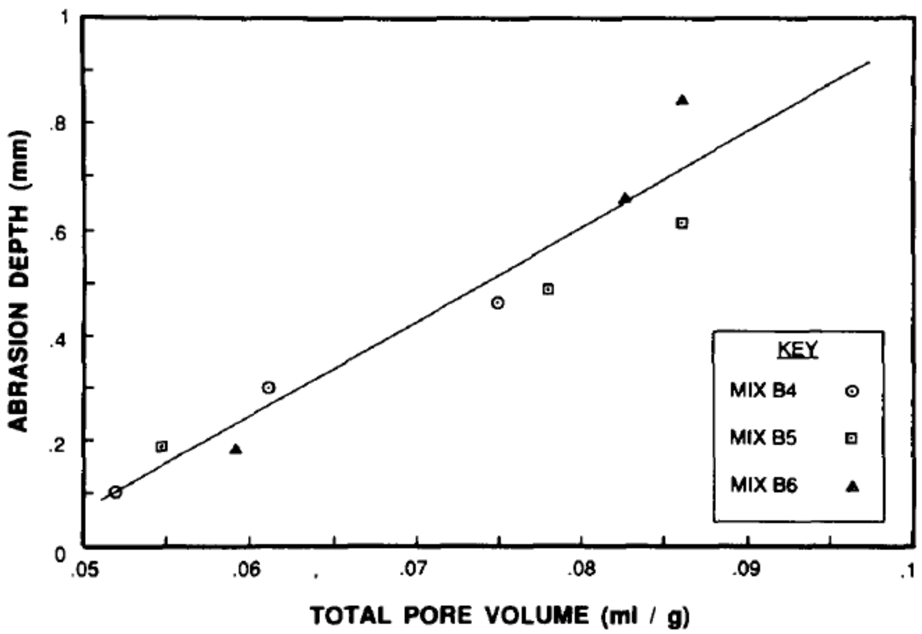

Figure 3. Abrasion depth verses total pore volume [45].

Abrasion depth decreased when micro hardness increased, as showed in Figure 4 , when micro hardness profile was experimented with model M12 hardness tester and observed in M41 photoplan microscope at various depth from 60μm to 16 mm for various specimens [45].

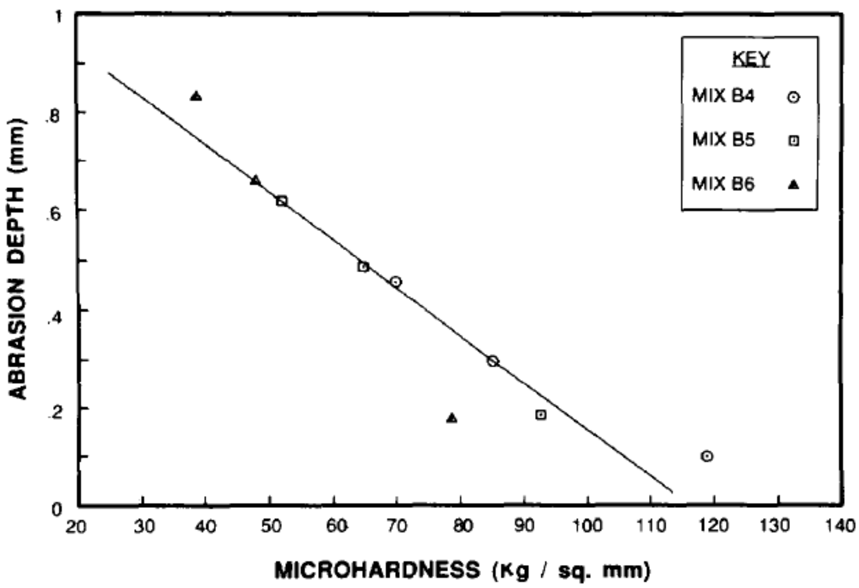

Figure 4. Abrasion depths versus micro hardness [45].

Abrasion resistance evaluated against three cracks pattern (0^o, 45^o and 90^o), four cracks with (0.5, 1, 2 and 3 mm) and two silica fume (5% and 10%). Stress distribution analyzed on specimen without crack was uniform whereas 11 times more, 26 times more and 34 times more stress distribution noted under abrasive condition on specimen having 0^o crack, 45^o crack and 90°crack respectively in direction of abrasive forces. Abrasive losses are noted more when crack is perpendicular to abrasive cutter and abrasion resistance of specimen of 0.5 and 0.1 mm cracks showed a decrease of about 66-125%, 59-08% and 59-98% for cracks in 0^o, 45^o and 90^o direction respectively. Crack width and crack direction affect the abrasion of concrete, reducing surface crack and cracks along abrasive forces direction are minimizing abrasive losses [46].

Average abrasion loss about 20 percentage was less when finishing stated at delayed time. Addition of water before every floating and delayed floating would prevent the forming of dense surface. It was recommended to remove all surface water during finishing and start delayed finishing improving scaling resistance. The effect of studied variables on abrasion resistance, application of linseed oil and delayed finishing avoid the abrasion loss up to 50 percentages [47].

6. Research Significance

Abrasion resistance of concrete is not only restricted with above mentioned parameters but also extend to site performance of concrete, durability and innovative field testing on concrete surfaces. Literature is suggesting laboratory testing on especially casted specimen only.

This paper is proposing an alternative methodology to existing, in which machine is assessing the surface wear resistance of not only casted concrete specimen of 300 X 300 X 100 mm in laboratory but also existing concrete pavement if machine place on pavement. Abrasion testing can be carried by portable abrasion testing machine to evaluate concrete in service concrete pavement or floors with tranquil typical arrangement. Machine with gear and electrical motor arrangement produces 33-35 revolutions per minute in wheels which are attached to vertical shaft as shown in Figure 5. Cast iron wheels of 32 mm thickness and 60 mm diameter are applying abrasive forces on concrete surface.

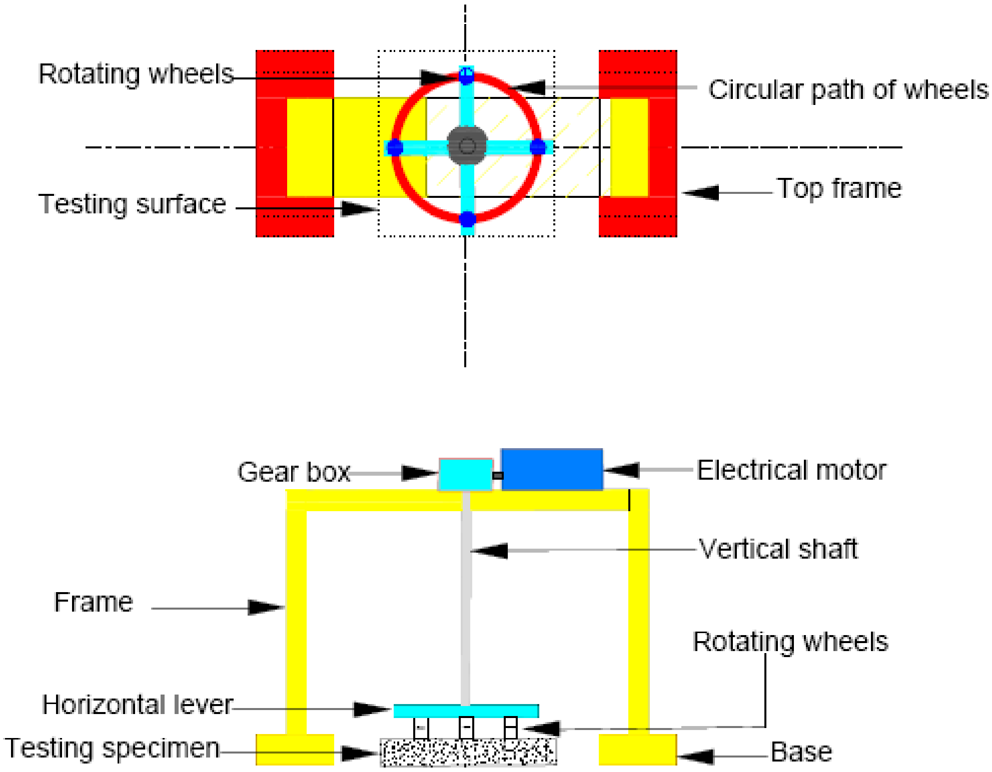

Figure 5. Abrasion Testing Machine.

Concrete Surface under evaluation has to be marked on an eight spots on circular path to observe abrasion depth after 500 revolutions, 1000 revolutions, 1500 revolutions and 2000 revolutions or after 15 minutes, 30 minutes, 45 minutes and 60 minutes.

Abrasion observed with set methodologies (i.e. IS1237 and IS9284) can be referred for proposed methodology (Portable Abrasion Testing Machine). Correlation could be developed between abrasion and ingredients of concrete, compressive strength, density, testing age of concrete. Ultimately this relations lead to evaluate durability and serviceability of concrete.

7. Conclusions

It is clear that understanding of mechanics of concrete surface fracture is crucial to mitigate its harmful effect on concrete. A variation in constituent of a concrete shows variation in properties including abrasion resistance which significantly depends upon the microstructural characteristics.

It is clear that, compressive strength plays vital role in abrasion resistance of concrete and followed by water-cement ratio, aggregate type, finishing and curing. Inclusion of tough aggregates, silica fumes and fibers are affecting on mechanical properties, possible to produce high abrasion resistive concrete as per requirement.

Abrasion assessment is influenced by testing procedure, age of concrete and environment conditions. The effects of environment and age of concrete on concrete surface is complex because of variable conditions.

Recommendations

Correlation between abrasion testing methodology and field performance of concrete is to be explored in detail.

More research is needed in suitability of test procedure, age of concrete and environment conditions, introduction of testing procedure like ASTM in India.

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