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CONTROLLED PERMEABLE FORMWORK (CPF) LINER: CONCRETE SURFACE QUALITY ENHANCER

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ABSTRACT

The durability of concrete structures primarily depends on the surface quality of the concrete, as it is the first line of resistance to penetration of aggressive agencies. Controlled permeable formwork (CPF) liner is an innovative material used for improving the quality of the cover surface zone of concrete. CPF liner drains mix water and entrapped air from the cover zone of concrete whilst retaining cement and other fine particles. This ensures triple benefit: (1) Reduced water-cement ratio, (2) Increased cement content, and (3) Decreased surface porosity in the surface zone of concrete. Though the CPF liner was introduced in Japan during the 1980s, its use and awareness are limited in Indian context, in particular. Most of the researchers have focused their attention to study the durability characteristics of CPF-lined-concrete. A critical review on the use of CPF liner is presented in this work. In addition, a comprehensive experimental study was conducted for the effect of CPF liner on the surface characteristics, depth of influence, and durability characteristics of CPF-concretes are discussed. In self-compacting concrete the synergetic effects add to the durability of concrete and eventually the sustainability.

Keywords: CPF Concrete, Covercrete, Heartcrete, Adhesive force, Blowholes, Pinholes.

INTRODUCTION

The present era of rapid technological growth occurred in all the frontiers has upturned our life style. Most of our traditional knowledge and concepts, which are proven and sustainable over the millennium, are gradually faded away from our memories, but fortunately not from our archives. The relevant example to this is the frantic efforts taken by the Indian cement industries to promote Portland pozzolana cement (PPC) in the market owing to higher margin. Most of our Engineers are of the opinion that PPC belongs to new generation. The Greeks and Romans were aware that the mixture of volcanic deposits, lime and sand yielded not only strong but durable mortars about 3000 years ago. Another vital knowledge, which remains elusive to the capture the attention of our modern Engineers, is the impact of water-cement (w-c) ratio.

In the early days, most of the concretes were "wet concrete mixes", practiced by the construction industry. That is, the concrete mixtures prepared with high water content were called wet concrete. Duff Abrams rule on w-c ratio was introduced in 1919, prior to that René Féret established a general rule relating the strength of concrete to the volumes of water in 1896[1]. (Neville 2003). Therefore, the early builders maintained high w-c ratio not due to the ignorance of its consequences, but otherwise the concrete could not be filled the forms fully and cast solidly. In order to contain the effect of high w-c ratio, absorptive boards were used to cast concretes. Early[2] has done a notable work along this line.

The needle or called poker vibrator was introduced during the late 1920s to consolidate the concrete[3] (Johnson 1941). Then started the era of "dry concrete mixes", that is, concrete mixtures were prepared with low(er) w-c ratio. Johnson[2] stated that the use of needle vibrator enabled to reduce the w-c ratio, however, all the troubles could not be eliminated. He believed that the use of absorptive forms even for the "dry concrete mixes" would eliminate most of the troubles.

Concrete was perceived as a homogenous and isotropic material until the presence of interfacial transition zone (ITZ) was realized. In macro scale, concrete can be considered as a homogeneous material, but it is definitely heterogeneous in micro scale[4,5] (Aïtcin 1998). Khokhrin (1973) reported the thickness of ITZ as 60µm. Bentur and Cohen[6] suggested the thickness of ITZ to be about 20 to 50 µm. Winslow et al. (1994) proposed a value in the range of 15 to 20 µm. Mehta and Monteiro[7] suggested a range of 10 to 50 µm for the thickness of ITZ. Based on the study on the roughness number, Zanpini, Jennings, and Shah[8] proposed a range of 96 to 128 µm. In terms of volume and size, ITZ is negligible compared to the bulk mortar matrix and aggregates. However, the essential properties of the concrete are significantly influenced by the characteristics of the ITZ and hence its presence cannot be ignored.

However high-performance concrete could be considered as a two-phase material as there is no longer a transition zone around the coarse aggregates. Disappearance of the transition zone makes high-performance concrete a true composite material with good stress transfer between the hydrated cement paste and the aggregate[4].

The transition zone forms a weak link due to the formation of a water film around the aggregate enhancing the w-c ratio. The water accumulation around the aggregates occurs due to the influence of adhesive forces. Similarly, when the fresh concrete is placed inside the formwork, the freely held water migrates towards the formwork and forms a water layer, which eventually causes adverse effects the quality of the concrete at surface level[9] (Kothandaraman and Kandasamy 2017). The 'concrete skin'[10](Kreijger 1987) or called 'covercrete'[11] (Halvorsen 1993) has been well known for a long time that the covercrete does not have exactly the same composition and microstructure as the interior of the concrete[3], called 'heartcrete'.

Now, taking into account of the effects of ITZ and covercrete, the concrete may be considered heterogeneous even on macro scale. The heterogeneity on macro scale may affect the performance of concrete under the influence of stress and more essentially the time bound behavior, such as creep and durability aspects significantly.

CONTROLLED PERMEABLE FORMWORK (CPF) LINER

Following the pioneering works of Early[2], Johnson[3], and Vidal & Blanks[12] on absorptive formwork, almost after about four and half decades, the CPF liner was reintroduced to the construction industry in Japan. Ichikawa, Yokota. and Katayama[13] tried textile lined formwork for the construction of Aseishi-Gawa Dam. Subsequently, Tanaka and Ikeda[14] and Horiya, Uno, and Katayama[15] studied the effect of permeable formworks on the durability of concrete.

CPF liners are the formwork system essentially intended to improve the quality of the surface zone of concrete. CPF liners are permeable to air and water, but prevent the escape of cement and other fine particles. This ensures the reduction of w–c ratio and increase in cement content in the surface zone of concrete. CPF liner creates a uniform surface, denser and less porous concrete surface/skin[17] (Kothandaraman and Kandasamy 2016). Nowadays CPF liner is manufactured using polypropylene fibre with certain variations in its quality[18] (Price 2000). Use of CPF liner ensures a smooth surface free from pin holes, blow holes and other blemishes.

It is usually recommended that to draw the requisite benefits the CPF liner has to be attached to the vertical faces of the formwork. Porewater pressure, hydrostatic pressure and pressure due to vibration[18,19] cause the water to travel towards the liner to get drained off. (Price 2000, Katayama & Kabayashi 1991).

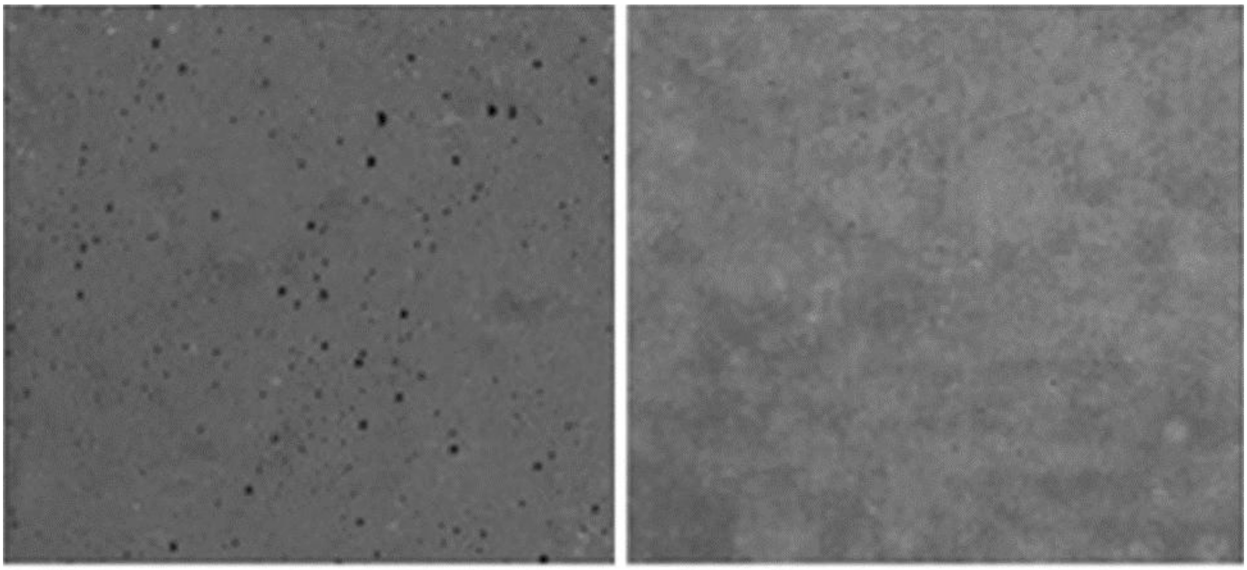
BENEFITS OF CPF LINER

SURFACE QUALITY

The first and the foremost benefit out of the CPF liner is the fine textured surface of concrete. The water and air which move towards the surface will get locked against impermeable formwork surface. This causes the surface defects. The Fig. 1 illustrates the improvements obtained out of CPF liner. Sometimes there will even be sand streaks and watercourses on the formed concrete surfaces.

The extent of surface quality improvement due to CPF liner has been illustrated in Fig.2. The red spots indicate the regions of surface irregularities. The use of CPF liner does not eliminate the entire surface defect. It has been reported that the average surface pores of CPF and IMF concrete specimens were 2% and 24 % respectively.

Apart from achieving a fine textured appearance of concrete superficially the CPF liner nurtures the hydration cement to a greater extent. While draining the water and air voids, the liner retains moisture to maintain high humidity within the surface zone, which is a conducive ambiance for the cement particles to hydrate to the maximum extent.



(a) (b)

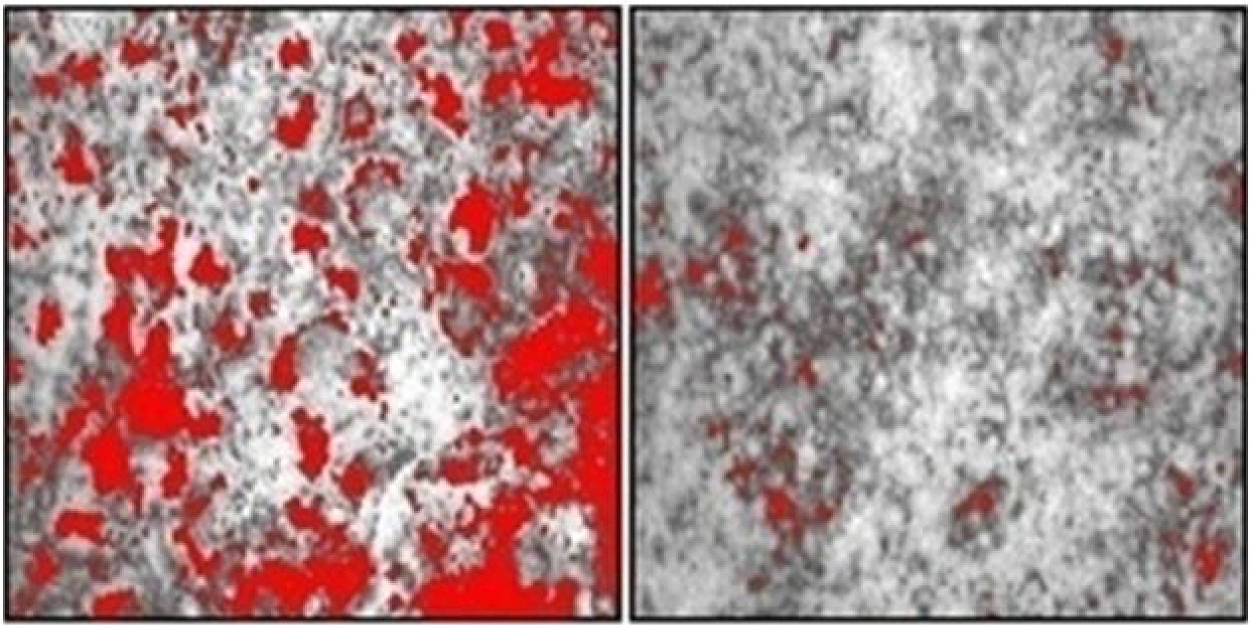
(a) Cast against impermeable formwork **(b) Cast against CPF lined formwork**

Figure 1: Surface quality of concretes[17]

EXTENT OF INFLUENCE OF CPF LINER

While using the CPF liner, water and air get drained off from the concrete. This process does not take place forcibly or intentionally but it occurs naturally. Under such circumstance it is pertinent to probe the extent of influence of CPF liner in enhancing the concrete quality. The durability of concrete essentially lies in the capacity of the cover concrete to contain the aggressive agencies from the ingress. Researchers and Scientists have been attempting to estimate the depth of influence of CPF liner measure from the surface since 1940s. But the opinions and results are widely varying.

The first ever finding on the depth of influence was reported by Vidal and Blanks[12]. They measured the w-c ratio at different depths of the mortar prepared against absorptive boards and reported that the decrease in w-c ratio was the greatest at the surface and progressively reducing toward the interior (Fig. 3). From this Figure it is noted that the absorptive formwork influenced the concrete quality to a depth around 22mm measured from the formed surface. Nearly after five decades, Kumagai, Arioka, and Tanabe[20] argued that when permeable forms were used the horizontal movement of water occurred within an extent of 100 to 200mm from the form. Kasai, Nagano, Sato, and Suga[21] investigated the depth of influence of CPF liner by measuring the pose-size distribution and the total volume of pores. They concluded that CPF had influenced about 30mm depth of concrete. Price and Widdows[22] investigated the w-c ratio at different depths by microprobe analysis. They found that at formed surface the w-c ratio was about 0.2, which increased to about 0.4 in the core region (Fig. 4) and they inferred that the depth of this transition was 20mm.



(a) Cast against impermeable formwork (b) Cast against CPF lined formwork

Figure 2: Typical concrete surface pore[17]

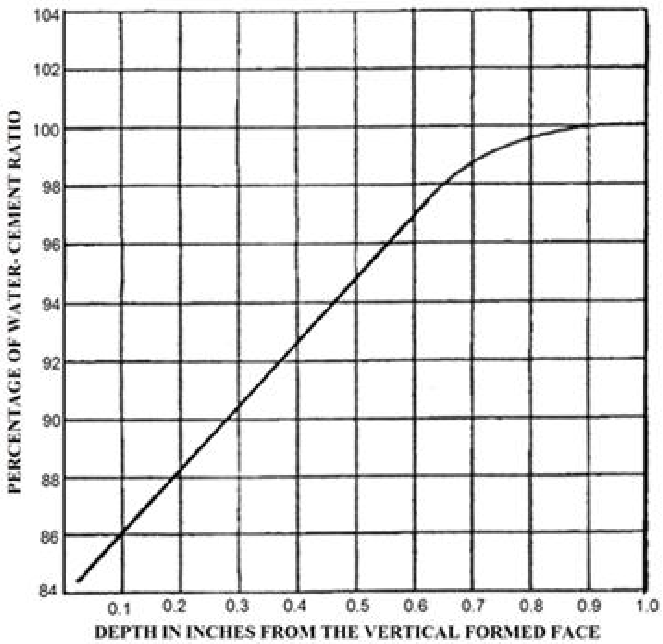


Figure 3: Typical curve showing reduction in w-c ratio of mortar against absorptive form lining[12]

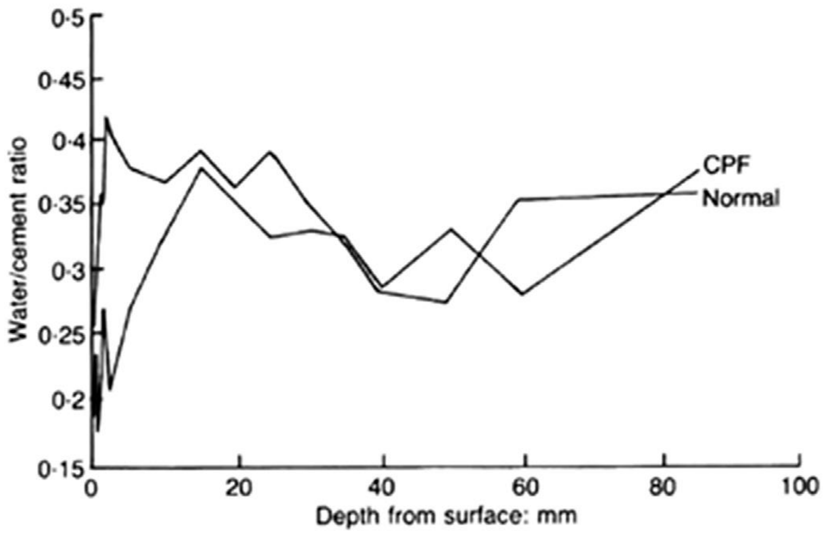
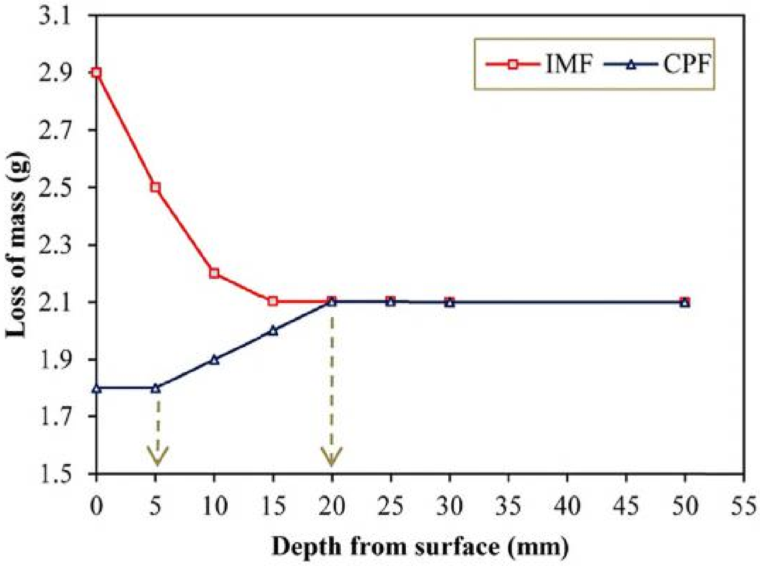


Figure 4: WATER/CEMENT RATIO OF CONCRETES[22]
(cast in steel moulds with and without CPF liner)

Shubel, Warrior, and Elliott[23] studied the tensile strength of concrete at different depths. They found that the tensile strength was decreasing from the formed surface and beyond 15 mm depth the tensile strength remained constant and concluded that the CPF liner densified the covercrete to a depth of about 15 mm. Liu, Miao, Chen, Liu, and Cui[24] conducted studies on pore structure of concrete over the cover zone by mercury intrusion porometery and concluded that CPF might not influence the concrete beyond 5mm. Recently, Kothandaraman and Kandasamy[9] studied the depth of influence CPF by conducting abrasion resistance at various depths (0 to 50mm) of concrete specimens cast against impermeable moulds and CPF lined moulds. They have reported that in conventional concretes 15mm depth of covercrete region remained softer than the core (Fig. 5). In CPF lined concretes 20mm thick covercrete remained harder than the core. In Fig. 6, the soft covercrete in conventional concretes and the hard covercrete in CPF concretes are clearly illustrated. Under abrasion, the mortar on the conventional concrete has been ripped off exposing the coarse aggregate. But in CPF concrete the mortar remained intact and due to abrasion the surface roughness had been smoothened. In addition, the section of the concrete specimens after abrasion at 10mm depth has also been scrutinized (Fig. 7). It is explained that at 10mm depth the surface was even in CPF concrete due to near equal hardness of both mortar and aggregates. But in conventional concrete the surface was uneven indicating that the mortar had lesser hardness than the aggregates.



(a) CPF Concrete (b) IMF Concrete

Fig. 5: Loss of mass under abrasion vs depth[9]

Figure 6: Formed concrete surface after abrasion[9]

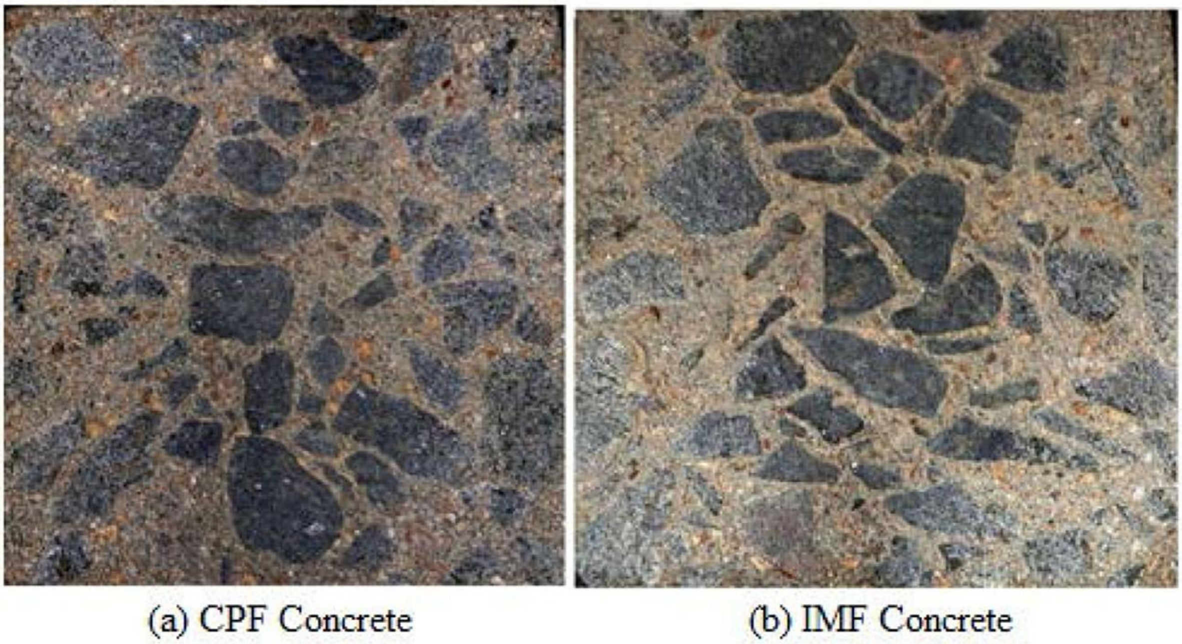


Figure 7: Concrete under abrasion at 10mm depth[9]

SELF-COMPACTING CONCRETE (SCC) CAST AGAINST CPF LINER

It has been essentially emphasized that the pressure caused due to concrete vibration, water and air migrate towards the form. In that case the usefulness of CPF liner cannot be exploited for technological benefits while using SCC. This is a very crucial factor to be considered in this context, because Johnson[3] has presented an excellent report on the investigations and experiences at Kentucky Dam. An important conclusion stated, in part, that: "….. *It is also highly probable that by increasing the w-c ratio and reducing the cement content, the surface produced will still be considerably better than we are obtaining today with lower w-c ratios and higher cement contents* . . ." Kothandaraman, Kandasamy and Sivaraman[25] have tried to verify the effectiveness of CPF against SCC and concluded that the improvements found in self-compacting concrete due to the use of CPF liner were similar with the improvements on conventional concretes reported by a number of researchers. It was also reported that the formed surface of SCC was not as smooth as that obtained in concretes cast with vibration (Fig 8). It has been explained that there two types of surface blemishes, pin holes and blow holes. The blow holes are due to water accumulation and pin holes are due to air. In SCC water migration took place due to the influence of adhesive forces. But for air due to the absence of the guiding force, vibration/pressure, the air bubbles were retained over the formed surface and hence the pin holes. A careful examination of the surface will reveal the truth. They further investigated the SCC to check its surface hardness. It has been inferred (Fig. 9) that CPF had influenced the surface hardness to the same extent as that had taken place in vibrated concretes

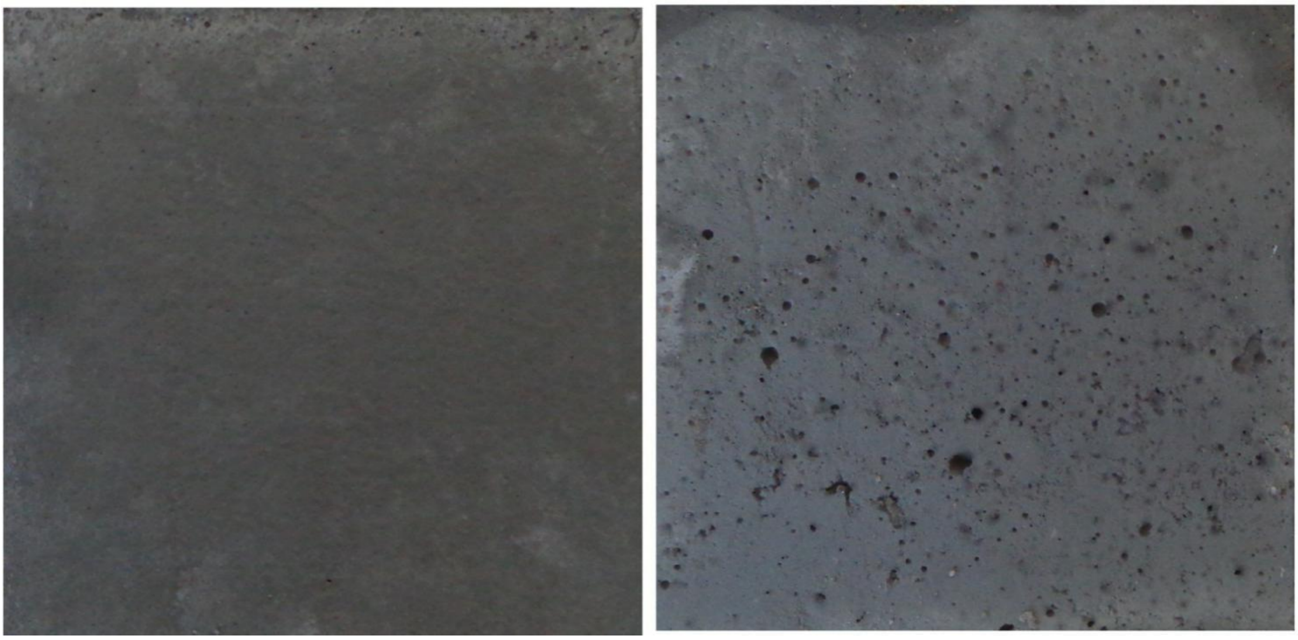


Figure 8: Formed surface of SCC[25]

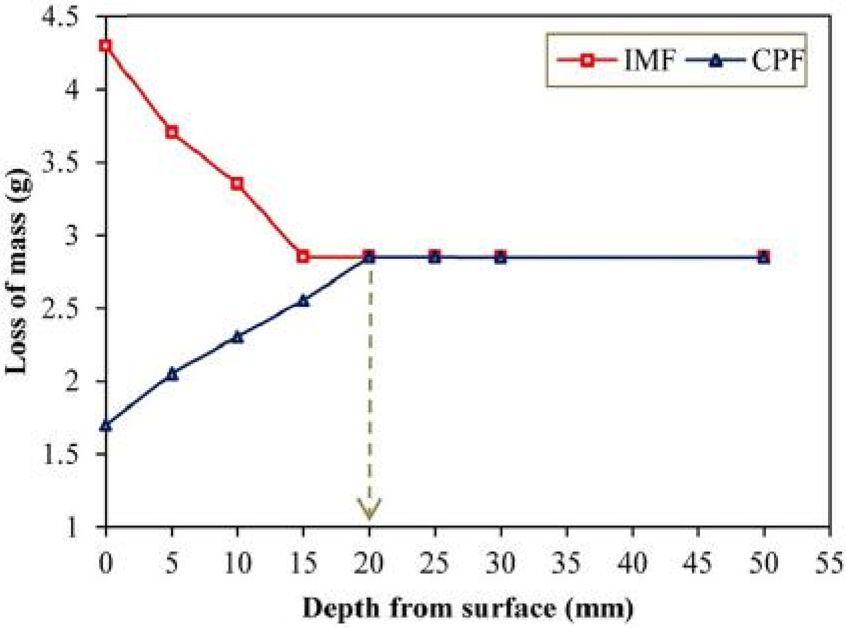


Figure 9: Loss of mass under abrasion vs depth in SCC[9]

CONCLUDING REMARKS

This review paper has brought out certain developments that have been taken place in the recent days on the improvement of concrete quality in general and in particular on the surface characteristics of concrete.

Though the use of CPF liner may boost the unit cost of concrete the technological benefits are significant and worth practicing.

The very face of the concrete quality is totally reversed. The conventional methods and specifications lead to enhance the bulk quality of the concrete, but fail to enhance the quality of covercrete. This is the crucial issue in the sustainable aspects of concretes. Further, under the aesthetic aspect also it gets additional facelift.

The thickness of the improved covercrete is now ascertained with great confidence and it is 20mm. This improvement is achieved identically both in vibrated concrete and SCC. The migration of water towards the formwork is guided by the influence of adhesive forces and the vibratory forces and pressure either due to porewater and/or hydrostatic do not appear to influence significantly.

The blowholes are due to the accumulation of water and the pinholes are due to air accumulation on the formwork. The airholes, however, do not adversely affect the performance of concrete in anyway.

Based on the findings of a vast number of reported research works it is clearly understood that the durability of the CPF concrete is dramatically enhanced over the conventionally cast concrete. Sustainability of the concrete materials is enhanced significantly and especially in SCC the synergetic effect plays still a very important role towards the sustainability.

The tensile strength of concretes is governed by the strength of the covercrete. Once the external surface of concrete ruptures then irrespective of the quality of heartcrete it eventually leads to failure. When the rebar is under severe to corrosion the covercrete is subjected to bursting forces. A weak covercrete formed due to impermeable formwork may lead to premature rupture of covercrete of even if the actual strength of the (heartcerete) concrete may be significantly higher. But in CPF concrete a relatively lower strength (heartcrete) concrete may offer better protection to rebar in two ways, firstly the tough coverete will delay the corrosion initiation period, and secondly the rupture of covercrete is delayed due to its higher tensile strength.

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