Conclusions from Task Group F: (Special Considerations)

N. Banthia
The University of British Columbia
2024-2324 Main Mall
Vancouver, BC, Canada V6T 1Z4

&

M. Maalej
Department of Civil Engineering
The National University of Singapore
1 Engineering Drive 2
Singapore 117576

This TG undertook the discussion of special issues that need consideration for a wider acceptance of HPFRCC by the user community. The discussion also resulted in identifying knowledge gaps and other hindrances limiting such acceptance.

Issue 1: Impact and Blast Performance

Test Difficulties and Standardization: A primary reason behind our lack of understanding of the impact resistance of HPFRCC is the complete absence of a standardized test technique. Several techniques have been developed—such as the *Drop Weight Test*, the *Swinging Pendulum Test* and the *Split Hopkinson Pressure Bar Test*—but they all produce different results for the same FRC. Clearly, data reported in the literature can not be compared as they are obtained using different impact machines with different specimen support systems, different energy loss mechanisms and different ways of generating high stress-rates, all of which have a strong influence on the results. In a recent study, it was demonstrated that even for the drop weight machines, as the capacity of the machine is varied, very different FRC toughness values emerge. Data from different labs therefore should only be compared with caution.

In most modern impact test systems, sufficient instrumentation is provided such that along with loads and deformations, additional specimen responses such as accelerations, velocities, etc., are also measured; these are needed for a proper analysis of the data. One major issue that needs to be dealt with is that of inertial loading. With some exceptions, all impact tests result in high accelerations in the specimen that manifest as inertial forces in measured loads. If such inertial loads exists, and are not accounted for, the results from impact tests may prove to be meaningless.

Equally important in impact tests is to provide a proper energy balance. It has been shown that at the point of peak load only 20% of the hammer energy is transmitted to the specimen and at failure this percentage rises only to about 50%; the rest of the energy remains within the machine as elastic and vibrational energy. This has significant implications, and one can not simply equate the hammer energy loss to that absorbed by the specimen.

<u>Size Effects</u>: One other area where significant new data are needed is in the area of 'Size Effects'. Recent tests have demonstrated that under impact, fiber reinforced concrete exhibits significantly more pronounced size effect than plain concrete.

<u>Strain-Rate Sensitivity and Brittleness at High Strain Rates:</u> HPFRCC is generally seen as somewhat less sensitive to strain-rate than ordinary FRC (Figure 1). A concerning trend, however, is the reduced toughness at high strain-rates. Data indicate that in the case of HPFRCC, the onset of brittleness occurs at a somewhat greater value of strain-rate, but occurs nonetheless (Figure 2). Exact reasons for this are not clear, and much more research is needed to understand the source of this incipient brittleness and to avert its occurrence. While this trend has been reported by many researchers, the threshold value of strain-rate at which this brittleness occurs varies from study to study.

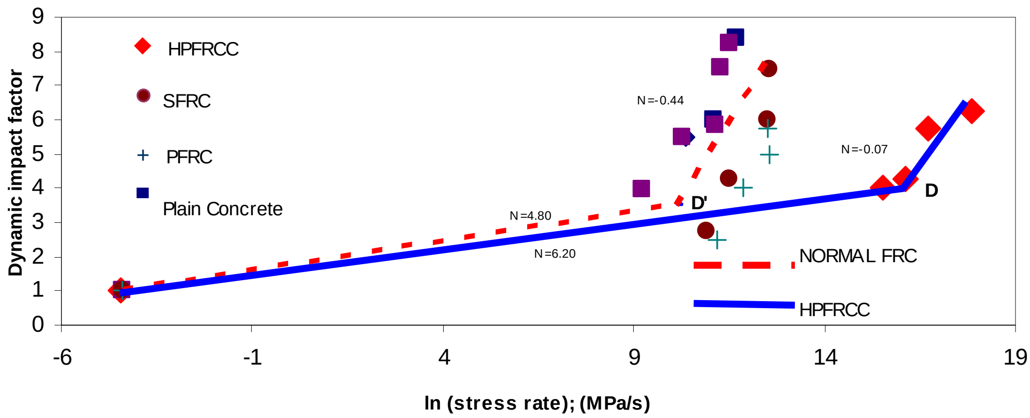

Figure 1. Stress-Rate Sensitivity of HPFRCC, Ordinary Steel Fiber Reinforced Concrete (SFRC), Ordinary Polypropylene Fiber Reinforced Concrete (PFRC) and Plain Concrete. Notice the reduced sensitivity of HPFRCC and the rightward shift of the 'knee'.

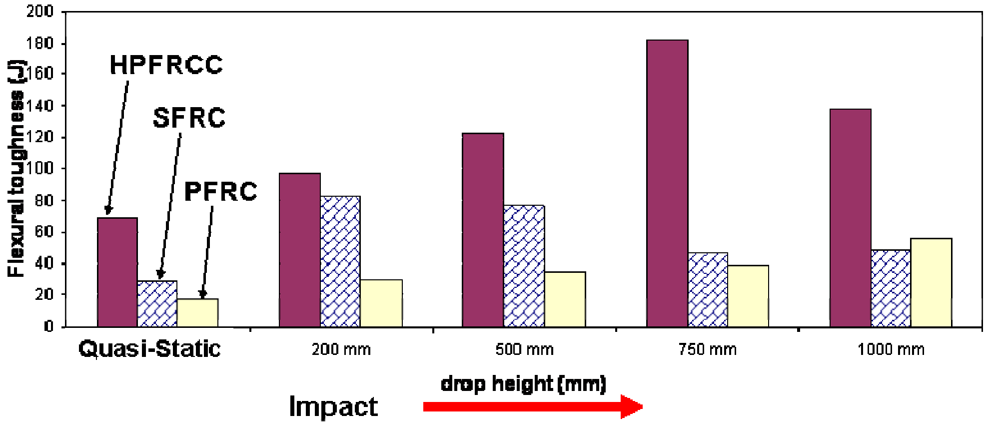

Figure 2. Reduced Toughness in FRC and HPFRCC at High Strain-Rates

Blast/Impact at High Temperatures: There is a practically no data on HPFRCC— and even FRC for that matter—under high temperature blast and impact. In the post 9/11 world, such data are highly critical for an acceptance of FRC for anti-terrorism purposes.

Shear Performance at High Strain-Rate: For use of HPFRCC in seismic applications, shear performance needs to be understood at high strain rates. Such information will also be very useful while designing HPFRCC shotcrete linings for rock-burst prone deep hard rock mines. At the same time, one needs to understand the influence of strain-rate on rebar-HPFRCC bond at both normal and high strain rates.

Issue 2 Fire Resistance

There is very little information on the fire resistance of HPFRCC. While there are indications that polymeric fibers with low melting points enhance fiber resistance by creating ducts from discharge of steam, the exact mechanisms are not understood. In particular the effects and relative importance of variables such as fiber melting point, decomposition temperature and fiber dimensions are not understood.

Issue 3: Fatigue

Very limited information exists so far as fatigue performance of HPFRCC is concerned. Size effects are very important and questions are raised if small specimens are representative of the performance of large elements in real life. There is also significant scatter in data and there exists a critical need to standardize fatigue tests. Such a standard test should specify allowable specimen sizes, range of applied loading frequency, load limits, type of machine, data acquisition protocol, test environment, and analysis procedure.

There is a sizeable group of experts that believes that designs should be explicitly based on fatigue performance and not on 'one-off' quasi-static values of strength. All elements are loaded in fatigue and strength reduction to account for fatigue is neither accurate nor sufficient.

Issue 4: Environmental Issues

A major problem facing the concrete industry is that its processes significantly promote global warming. One ton of cement production releases nearly one ton of CO_2 in the atmosphere along with large quantities of NO_x gases. As most high performance cement-based materials involve the use of large quantities of cement, focus must be on reducing cement consumption in such materials and replace it with industrial by-products such as fly ash. While cement reduction makes perfect environmental sense, on the performance side, it is not clear if the industry can settle for set delays and slow strength gains in such ‘greener’ materials. On the fiber side, HPFRCC should consider the use of natural fibers (cellulose, flax, etc.) as well as recycled fibers.

Concrete accounts for over 75% of all construction materials by weight, and along with increased consumption, there is also an increase in the amount of waste concrete. Industrialized countries on an average produce nearly 1 ton of waste concrete per capita per year, large portion of which could easily be recycled back into new concrete in the form of recycled aggregates. Unfortunately, while such ‘green’ concretes suffer from inadequate strength, high shrinkage and inadequate durability, one can devise smarter ways of circumventing these problems.

Issue 5: Selective/Strategic Use of HPFRCC

HPFRCC exhibits excellent mechanical performance including toughness, ductility, energy absorption, crack control, and durability. However, HPFRCC, in almost all forms, is more expensive than normal FRC and significantly more expensive than plain concrete. Its use is therefore justifiable only when loading or environmental conditions warrant properties that are not otherwise available in normal FRC and certainly not available in plain concrete. However, there are a number of situations where one can contemplate the use of HPFRCC in a strategic manner and in critical/selective locations of the structure such that the use of HPFRCC may produce cost savings over the service life of the structure. Such critical uses include: white topping in bridge decks, ductile HPFRCC strip at pavement joints, segmental column with HPFRCC top/bottom segments, HPFRCC layer around steel for corrosion, parts of the structure carrying concentrated loads, impact face of offshore buffer elements, high shear locations such as corbels, etc.