# 92+ GRADE HIGH PERFORMANCE CEMENT: SOLUTION FOR NEXT MILLENNIUM

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*The production of special and custom- made cements is becoming one of the powerful trends of a modern market. New types of high- tech cements based on high performance cement technology can be concerned as one of the promising materials for future construction projects. Developed approach to control the cement properties allows significantly improvement of high performance cement based systems strength and durability.*
*High strength and durability of high performance cement are provided by the application of silica fume based complex admixture. This phenomenon allows to use the required amount (up to 50%) of a granulated blast furnace slag as mineral admixture in the cement composition that results in the increasing of chemical and thermal resistance. The analysis of a wide scale investigation demonstrates the opportunity to produce high performance cement and mortars with compressive strength comprised between 95 and 145 MPa, respectively. High performance cement based mortars possesses low permeability, high resistance to chemical attack and thermal resistance.*

## *Introduction*

There are numerous of examples for successful development and application of high strength and high performance cement based materials, when basic principles of portland cement-silica fume-superplasticizer systems were formulated by H. Bache [1]. Extensive work of many research teams worldwide allowed to transfer the laboratory findings in this area to practice [2-3].

New types of high- tech cements based on high performance (HP) cement technology (PCT/TR98/00008 WO9854108A1: Complex Admixture and Method of Cement Based Materials Production) can be concerned as one of the promising materials for future construction projects [4-7]. In HP cement and mortars high strength (up to 145 MPa) and durability are provided by the application of silica fume based complex admixture. This phenomenon allows to utilize a large quantity (up to 70%) of indigenous mineral admixtures in a high volume mineral admixtures (HVMA) cement composition. The natural pozzolanic

materials, sand, limestone, granulated blast furnace slag, fly ash, broken glass and ceramic can be used as indigenous mineral admixtures in the cements. This approach allows manufacturing of a wide range of special and custom- made cements with unique performance [4-7].

The main idea of the HP cement technology can be presented as physical-and-chemical activation of the cement grinding process with complex admixture. The increasing of dispersion and reaction ability of the cement components, as well as modifying of the cement surface with complex admixture are achieved due to complex admixture formulation. The following processes are providing HP cement phenomenon:

- pulverisation of clinker and mineral admixtures due to development of micro-distractions,
- creation of high active amorphous structures and pre-hydrates, and
- physical-and-chemical modification of the minerals by complex admixture.

The HP cement is manufactured through blending and grinding of a certain amounts of clinker, gypsum, complex admixture and mineral admixture of industrial or natural origin. There are some alternatives in HP cement production modes:

- basic HP cement (Type A) production mode, and
- blended HP cement (Type B) production mode.

Basic Type A production mode is to manufacture HP cement by grinding of clinker, gypsum and complex admixture combination. Blended production mode covers the wide range of HP cements with mineral admixture. The mineral admixture content in blended HP cement depends on required level of properties and type of the admixture used. Research results demonstrated the opportunity to produce the HP cements with mineral admixture content closed to standard limitations (within the range of 25-50%), as well as to extend frames of mineral admixture application for HVMA cement manufacture. Some new types of mineral admixtures such as sand, broken glass and ceramic can be utilized as a component of the blended HP cement [4-5]. The usage of granulated blast furnace slag (GBFS) in blended HP cement composition provides very high resistance to chemical attack. Sulphate resistance of these systems is better than existing requirements for sulphate resistance cement due to super low permeability and more resistant chemical structure. Wide scale investigations of strength behaviour of the system is demonstrating the opportunity to produce blended HP cement with compressive strength more than 80 MPa for GBFS content up to 50%.

## *Chemical Composition*

Chemical composition of HP cement depends on the type and composition of components used. The chemical composition of HP cements (HPC) in comparison with normal portland cement (NPC) and GBFS used are presented in Table 1.

**Table 1. Chemical composition of HP cements**

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ | L.O.I |
|---|---|---|---|---|---|---|---|---|---|
| NPC | 19.44 | 4.78 | 3.57 | 63.74 | 1.90 | 0.77 | 0.21 | 2.70 | 2.41 |
| GBFS | 40.09 | 11.48 | 1.56 | 31.85 | 9.49 | 1.00 | 0.00 | 2.10 | 0.17 |
| HPC-A | 28.47 | 4.18 | 3.36 | 55.01 | 1.89 | 1.02 | 0.38 | 2.61 | 2.83 |
| HPC-B | 34.28 | 7.83 | 2.46 | 43.43 | 5.69 | 1.01 | 0.19 | 2.35 | 1.50 |

## *Physical Properties of HP Cement*

The comparison results of HP cement (HPC) and normal cement (NPC) in accordance with corresponding ASTM procedure are summarized in Table 2. The particle size distributions of investigated cements are presented in Fig. 1.

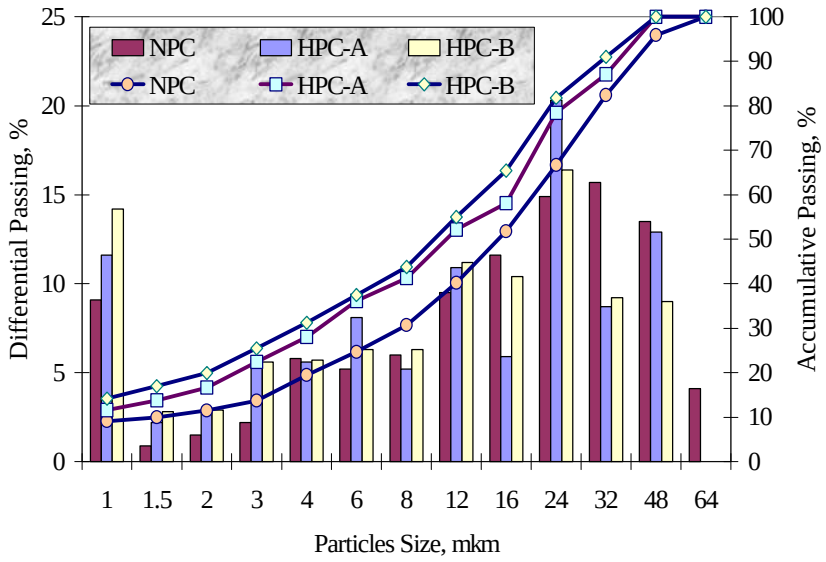


**Figure 1. Particles Size Distribution of Investigated Cements**

**Table 2. Physical Properties of HP Cement**

| | Fineness | | Setting Time min | | Normal Consistency % | Compressive Strength, MPa @ age, days | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Blaine $m^2/kg$ | 45 μ % | Initial | Final | | 1 | 2 | 3 | 7 | 28 | 90 |
| NPC | 310 | 8.50 | 165 | 205 | 27.1 | 26.2 | 36.4 | 42.4 | 48.5 | 57.1 | 64.7 |
| HPC-A | 570 | 5.40 | 100 | 145 | 18.5 | 44.3 | 55.9 | 62.2 | 74.1 | 94.4 | 96.2 |
| HPC-B | 580 | 5.20 | 175 | 225 | 17.5 | 35.2 | 44.8 | 54.2 | 65.6 | 92.7 | 105.5 |

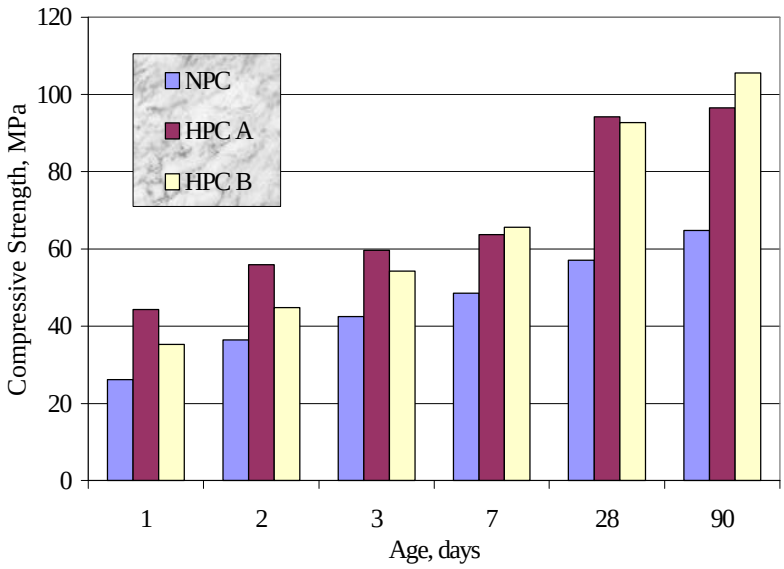


**Figure 2. HP Cement Strength Development**

HP cement possesses a 28- day compressive strength, which is at least 65% higher than the strength of normal strength. Early age strength development of the HP cement allows to classify this cement as a super rapid hardening cement. HP cements demonstrated an ability to develop a long-term strength, especially, in case of Type B based on 50% of GBFS (Fig. 2).

## *Strength of HP Cement Based Mortars*

High strength phenomenon allows to apply the HP cement for production of the wide range of mortars. The 28-day compressive strength of HP cement mortars was found in the range of 40 to 145 MPa depending on sand to cement ratio (S/C). The test results of strength behavior of Type B HP cement based mortars in comparison with normal portland cement mortars in accordance with ASTM C389 "Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete" are summarized in Table 3. According to the obtained results, the strength of HP cement mortars at S/C=7 can be compared with the strength of NPC mortars at S/C=5 (Fig. 3).

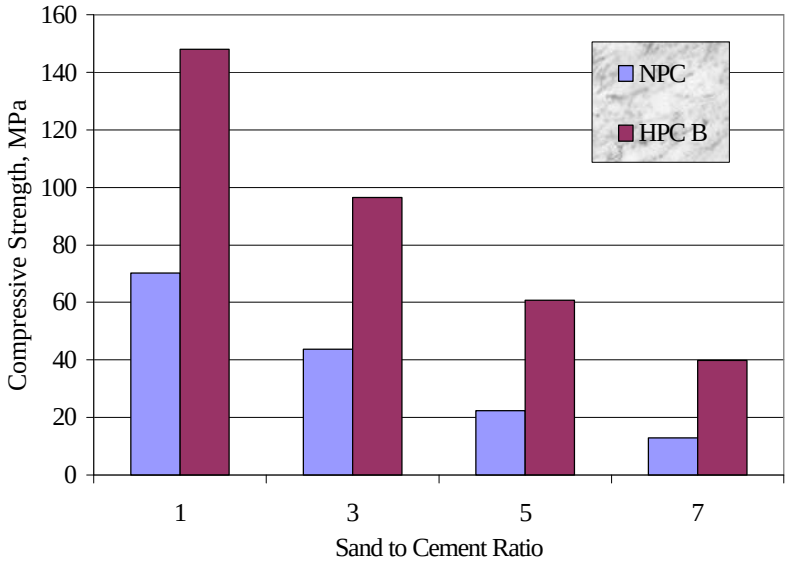


**Figure 3. Strength of HP Cement Based Mortars**

**Table 3. Strength of HP Cement Based Mortars**

| | 28-day Flexural Strength, MPa @ S/C | | | | 28-day Compressive Strength, MPa @ S/C | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 3 | 5 | 7 | 1 | 3 | 5 | 7 |
| NPC | 12.2 | 8.9 | 5.3 | 3.7 | 70.2 | 43.8 | 22.3 | 12.9 |
| HPC-B | 24.5 | 12.8 | 8.3 | 5.9 | 148.1 | 96.4 | 60.8 | 39.8 |

## *Durability of HP Cement Based Systems*

Water Absorption and Impermeability

Permeability of hardened cement stone is one of the basic properties determining the durability of concrete. Due to low W/C of HP cement based system, the capillarity is very low and water absorption value was found in the range of 0.3-0.8%. In case of usage of GBFS for Type B HP cement, an additional reduction of pore size takes place. These factors provide impermeability of HP cement system at low diffusion coefficient of $1.2\text{-}0.8*10^{-10}$ cm/s.

Resistance to Chemical Attack

Very low permeability of HP cement systems provides high resistance to chemical attack. Investigation of acid resistance of mortars based on GBFS Type B HP cement demonstrated the opportunity to apply such systems in HCl solutions for 1½ month without risk of failure, while normal cement samples were completely destroyed after two weeks.

Freezing and Thawing Resistance

HP cement based mortars possess excellent freezing and thawing resistance. There was no visible destruction of HP cement samples after 140 cycles of freezing and thawing at

-50 $^0$C. Bar expansion was 0.02%, than normal portland and GBFS cements length change was indicated at 0.1% after 45 and 35 cycles, respectively.

Thermal Resistance

HP cement mortars demonstrated high resistance to elevated temperatures. Only 10-20% reduction of strength was found for the GBFS Type B HP cement mortars after step by step temperature rising (each step was 100$^0$C with 24- hour exposure). Under the same conditions mortars based on normal cement have lost more than 50% of strength 500$^0$C.

## *Conclusions*

1. HP cements developed in accordance with presented approach have demonstrated better performance than existing normal cement in such aspects as strength at all age of hardening, permeability, resistance to chemical attack, freezing and thawing resistance, resistance to elevated temperature.
2. HP cement technology allows to utilize high volumes of mineral admixtures like GBFS for manufacturing of the cement based products with high strength and significantly improved durability.
3. High level of HP cement properties allows to recommend this relatively new material for application in the unique projects such as high-rise buildings, airport runway structures, bridges, marine and offshore structures, tunnels, parking desks, shotcrete and repairing of structures, underwater concrete, special floors.

The application of presented approach is not limited by materials with high strength or extreme durability, but also can be used for utilisation of industrial by-products and waste or engineering of composite materials with desired properties, such as low thermal expansion, electrical conductivity, light-reflecting and many others. HP cement development team welcomes inquiries from potential partners for licensing, joint application and collaborative research.

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