# THE 13TH INTERNATIONAL CONFERENCE ON QiR (QUALITY in RESEARCH)

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ORGANIZED BY :

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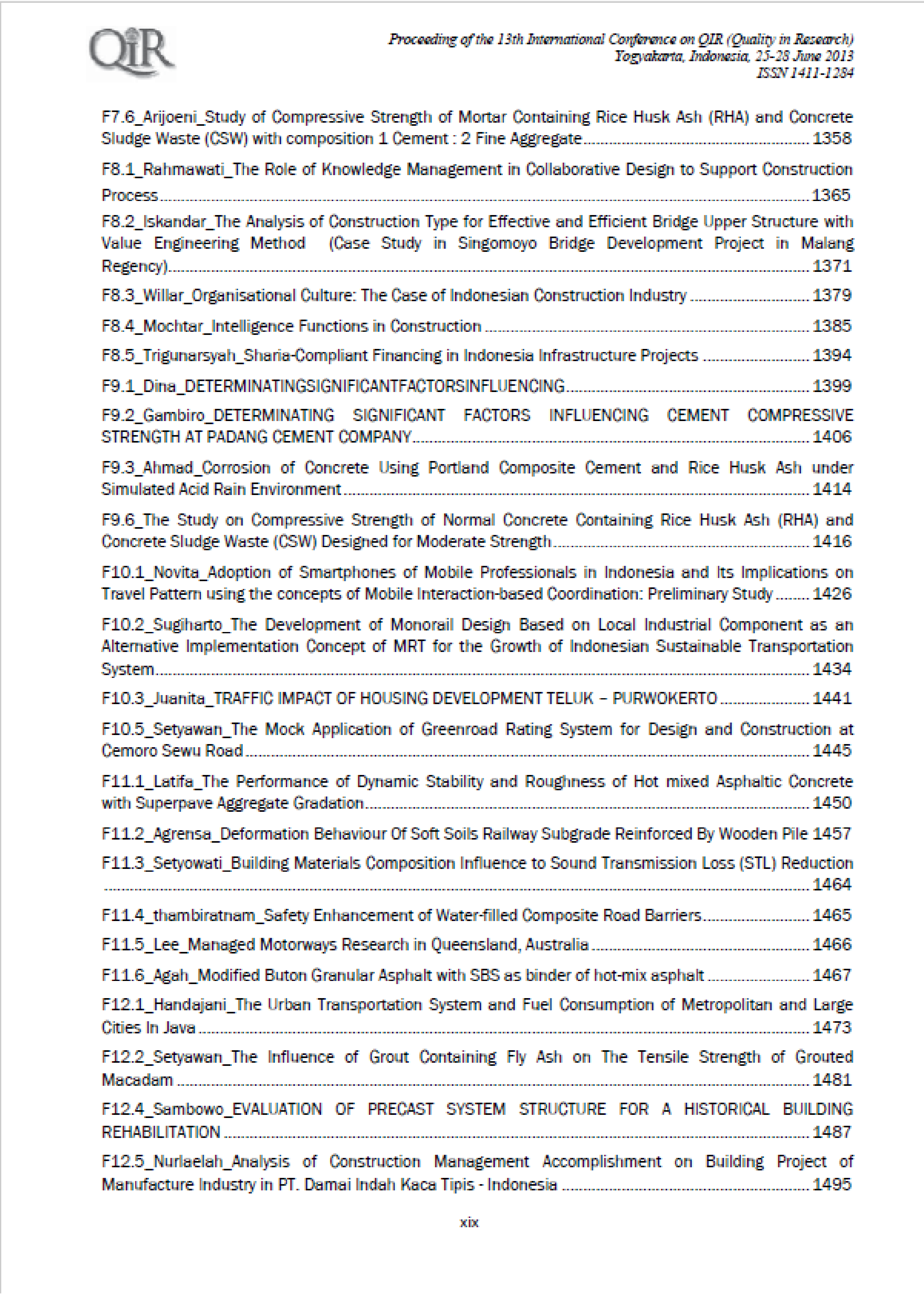
## PROCEEDING

ISSN 1411-1284



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# The Influence of Grout Containing Fly Ash on The Tensile Strength of Grouted Macadam

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## ABSTRACT

*Grouted Macadams are manufactured by producing a very open porous asphalt skeleton and filling the voids with selected cementitious grouts, the final product is combination of the flexibility of the bituminous component with the strength and rigidity of the cementitious component. A range of cementitious grouts was formulated using a variety of binders including ordinary Portland cement, silica fume and fly ash. The grouts were designed to provide improved strength and performance characteristics with reduced water/binder ratios, whilst maintaining high workability. This was achieved with the aid of chemical admixtures that allowed the grouts to penetrate the porous asphalt skeleton by gravitational. The formulated cementitious grouts attained high strength characteristics (90-120 MPa at 28days), with the pozzolanic materials silica fume and fly ash, providing improved permeability and shrinkage properties. This paper is discussing the influence of grout properties containing fly ash especially on the indirect tensile properties of grouted macadam. It is concluded that the indirect tensile strength of grouted macadams were greatly affected by the cementitious grout type, in general the higher the compressive strength of the cementitious grout, the higher the tensile properties of the hydrated grouted macadam.*

**Keywords**

*Grouted macadam, fly ash, indirect tensile strength*

## 1. INTRODUCTION

The tensile properties of materials govern the cracking behaviour and affect other properties such as stiffness and fatigue behaviour of the materials. Tensile strength can be determined either by direct tensile tests or by indirect tensile tests such as flexural or split cylinder tests. Due to the difficulty in testing, only limited and often conflicting data are available on direct tensile tests. It is often assumed that the direct tensile strength of concrete is about 10% of its compressive strength [1].

The indirect tensile test was introduced to measure the tensile properties of pavement materials due to its many practical advantages as summarised by Kennedy [2]:

(1) the test is relatively simple to carry out,
(2) the type of specimen and the equipment are the same as those used for other testing, for instance using cylindrical specimens,
(3) failure is not seriously affected by surface conditions and is initiated in a region of relatively uniform tensile stress,
(4) the test can be conducted under static or repeated loading conditions, and provides information on:
    a. the tensile strength, modulus of elasticity, and Poisson's ratio for both static and repeated loads,
    b. fatigue characteristics,
    c. permanent deformation characteristics of pavement materials.

The indirect tensile test is carried out on a cylindrical specimen by loading it with a single or repeated compressive load which acts parallel to and along the vertical diametrical plane of the specimen. This loading system develops a relatively uniform stress perpendicular to the direction of the applied load and along the vertical diametrical plane, thus ultimately causing failure of the specimen by splitting along the vertical diameter. The stress state in the surroundings of the centre of the circular face of an indirect tension specimen is similar to the stress state that occurs at the underside of a bituminous road layers.

Grouted macadams have visco-elastic properties similar to flexible pavements. The tensile properties of grouted macadams covered in this investigation were mainly the indirect tensile strength (ITS), the indirect tensile stiffness modulus (ITSM) and the indirect tensile fatigue test (ITFT) [4] These tests were conducted at several temperatures and at a range of curing ages. Flexural strength testing was additionally carried out to enable a direct comparison to be carried out between the flexural strength of grouted macadams and those of a typical concrete at 28 days curing. Grouted macadam test results were thus compared to the properties of bituminous mixtures and concrete.

## 2. RESEARCH METHOD

### 2.1 Materials preparation

### 2.1.1. Materials for cementitious grouts

The cement used through out this investigation was ordinary Portland cement (OPC) supplied by Castle Cement Limited. The OPC complied with requirements of BS 12 (BS 1996). The properties of OPC are presented in Table 3.7. Quartzitic sand obtained from Tyhram Hall Quarry supplied by Tarmac Northern Ltd. was sieved, and the material passing 300μm was used as fine sand for the cementitious mortar. The water used in this investigation was tap drinking water from Yorkshire Water. The fly ash used in this investigation was produced at Drax Power Station and supplied by National Power plc. U.K. The ash conforms to BS 3892: Part 1 (BSI 1997). Table 3.6 gives the chemical composition of the Fly Ash use. Powdered silica fume was supplied by Elkem Chemical. The chemical composition is also presented in Table 1.

Table 1: Chemical composition of OPC, fly ash (FA) and silica fume (SF).

| | *Ordinary Portland cement %* | *Fly ash %* | *Silica fume %* |
|---|---|---|---|
| $SiO_2$ | 21.03 | 49.9 | 90.0 |
| $Al_2O_3$ | 4.73 | 26.5 | 1.21 |
| $Fe_2O_3$ | 2.93 | 8.1 | 3.87 |
| CaO | 63.63 | 1.7 | 0.34 |
| MgO | 2.67 | 1.3 | 1.43 |
| $SO_3$ | 3.00 | 0.9 | 0.31 |
| $K_2O$ | 0.65 | 3.6 | 1.49 |
| $Na_2O$ | 0.30 | 1.5 | 0.46 |
| Loss on Ignition | 0.97 | 3.8 | 2.17 |

### 2.1.2 Superplasticizer

The use of chemical admixtures is an essential requirement for the production of flowable high performance slurries. A superplasticiser (SP) based on modified polycarboxylic ether was used with all the cementitious mixes, which complied with BS 5075: Part 3 (BSI 1985). This chemical admixture was supplied by Feb MBT Ltd. in liquid form. Technical data as supplied by supplier is presented in Table 2.

Table 2: Properties of superplasticiser

| | |
|---|---|
| Appearance | Viscous liquid |
| Colour | brown |
| Specific gravity | 1.1 |
| pH | 6 |
| Alkali content (as $Na_2$ equivalent) | < 5g/l |
| Chloride Ion content | < 0.1% w/v |
| Hazardous ingredients | none |

## 2.2 Cementitious grout mixture design

### 2.2.1 Binder compositions and fresh properties of the grouts

It is now generally accepted that mineral and chemical admixtures are essential requirements for the production of concrete. In addition to their dramatic effect of on the reduction of mortar porosity, they improve the packing capacity at the interface with the aggregates and thus create a tighter pore structure of the composite [5].

Three main cementitious binders were used in this investigation with the composition and binder/cement ratios as shown in Table 3. The first type was used as a control mixture by incorporating 100% ordinary Portland cement (OPC). The second type was formulated by adding 5% of silica fume (SF) and the third cementitious binder was formulated by adding 30% of fly ash (FA).

Table 3: Composition and fresh grout properties of the different grouts used in this investigation

| *Grout* | *Composition* | | *Super-plasticiser* | *W/B** | *Workability index (seconds)* | *Setting time* | |
|---|---|---|---|---|---|---|---|
| | | | | | | *initial* | *final* |
| OPC | OPC | 100 | 1% | 0.28 | 9.50 | 3h. 05min. | 4h. 10min. |
| SF | OPC: SF | 95: 5 | 1% | 0.28 | 9.10 | 3h. 35min. | 4h. 30min |
| FA/SF | OPC: FA: SF | 65: 30: 5 | 1% | 0.28 | 10.32 | 3h. 50min | 4h. 55min |

W/B*= water/binder ratio, biner is defined as blend of OPC or OPC and mineral admixtures

The proportions of mineral admixtures as cement replacement can vary from 5% to 80% by mass of cement. In normal structural concrete containing 5% silica fume addition, the water demand is normally increased to maintain the desired workability otherwise a superplasticiser is added [6]. In this investigation, the water/binder ratio was selected to produce grout flow times between 8-11 seconds as measured using the Leeds flow cone. Several initial trials indicated that by adding 1% superplasticiser by mass of binder to a grout with a water/binder ratio of 0.28 produced grouts that had satisfactory workability. Ease of impregnation was also assessed using dummy porous asphalt samples to ensure full depth penetration of the grout into the porous asphalt.

### 2.2.2. Strength properties

Both silica fume and fly ash are industrial waste by products and are very well known as mineral admixtures or supplementary cementing materials. In many cases these mineral admixtures react more slowly than OPC, giving increased strength and improved impermeability to the hardened cement paste at later ages.

The strength property of various cementitious grouts, at various curing ages is presented in Table 4. and graphically shown in Figure 1.

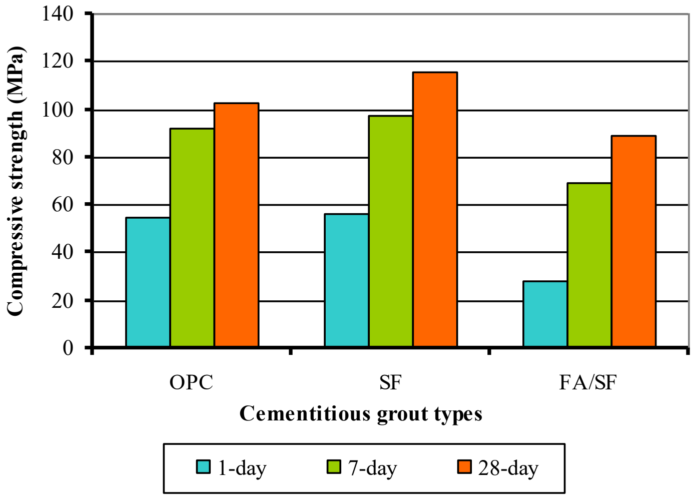

Figure 1: Compressive strength of three main types cementitious grouts

Table 4: Compressive strength of the cementitious grouts

| *Grout* | *Compressive strength (MPa)* | | |
|---|---|---|---|
| | 1 day | 7 days | 28 days |
| OPC | 55 | 96 | 102 |
| SF | 56 | 97 | 108 |
| FA/SF | 28 | 69 | 90 |

All the hydrated grout mixes showed little variation in bulk density (density values ranging from 1.85 to 2 g/cm$^3$). However, the compressive strengths varied widely depending on the grout composition. As shown in Figure 1 the highest compressive strength values were found with the SF grout mixture. The 1-day compressive strength was 56 MPa, which increased to about 108 MPa at 28-days. The OPC showed similar strength to that of SF whereas fly ash grouts (FA/SF) resulted in a lower compressive strength at 1-day, but achieved a reasonably high value at 28-days. Both SF and FA are pozzolanic materials, which provide additional hydration products through their pozzolanic reaction to densify the cementitious matrix and improve the micro-structural properties [7]. Whilst Fly Ash adversely affects the strength gain at early ages, it contributes more to the strength development in the long term [8].

### 2.2.3 Performance properties

The performance properties of cementitious grouts at 28 days are presented in Table 5. Drying shrinkage results of the cementitious grouts up to 180 days are presented in Figure 2. The results, as shown in Table 5, indicate little variation within the calculated porosity values for the different cementitious binders, overall the results ranged between 29 and 31%. The effect of SF and FA replacement can be seen more clearly from the permeability and shrinkage results. Both replacement types are known to refine the pore structure of the cementitious composites and hence improve the performance properties. The pore refinement effect was reflected in the results, as both grout mixtures exhibited lower permeability and shrinkage than the OPC grout. The reduction in permeability was about 60% for the SF and 35% for the FA/SF, when compared to the OPC mix. SF and FA also reduced the drying shrinkage values by about 12-15%.

Table 5: Performance properties of the cementitious grouts measured at 28 days.

| *Grout* | *Porosity (%)* | *Oxygen permeability ($10^{-17}$ $m^2$ )* | *Shrinkage (micro-strain)* |
|---|---|---|---|
| OPC | 29.4 | 3.05 | 1803 |
| SF | 29.8 | 1.17 | 1518 |
| FA/SF | 30.9 | 1.95 | 1578 |

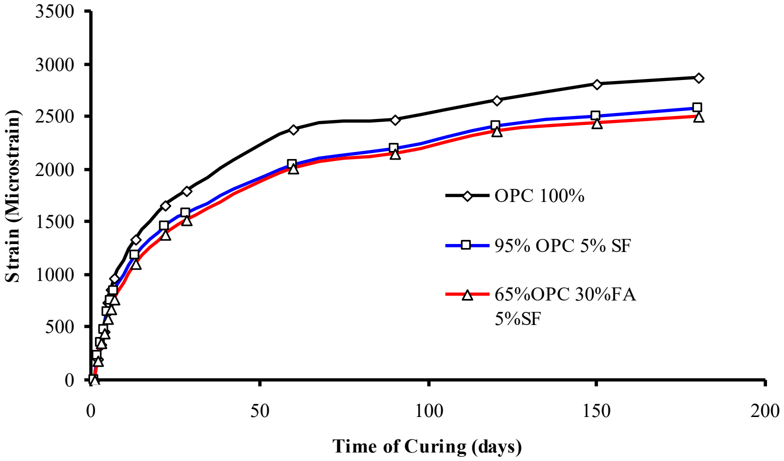

Figure 2: Drying shrinkage of the main type of cementitious grout up to 180 days

### 2.3 Indirect Tensile Strength Test

The indirect tensile strength test was conducted according to BS:99/108553 BS EN 12697-23 “Determination of the indirect tensile strength of Bituminous Specimens” (BSI 1999). The test was carried out using a Marshall loading frame fitted with a 12.5mm wide concave surface loading strip. The cylindrical specimens are subjected to compressive loads, which act parallel to and along the vertical diametrical plane. This creates uniform tensile stresses perpendicular to the direction of applied load and along the vertical diametrical plane, which ultimately causes the specimen to fail by splitting along the vertical diameter. Based upon the maximum load carried by a specimen at failure, the ITS is calculated from the following equation:

$$ITS = \frac{2 \times P_{\max}}{\pi \times t \times d} \qquad (.1)$$

where*:* $ITS$ = indirect tensile strength (kPa), $P_{max}$= maximum applied load (kN),
$t$ = average height of specimen (m), $d$ = diameter of specimen (m).

The tests were conducted at three temperatures (5, 20 and 60ºC) to stimulate various pavement conditions. To investigate the early strength development, the tests were also carried out at three curing ages (1, 7 and 28 days).

## 3. RESULTS AND DISCUSSION

Grouted macadam specimens produced using the same hot mix limestone porous asphalt skeleton with three types of cementitious grouts were subjected to the ITS test at three different temperatures. The tests were conducted after 28 days of curing. The results are presented in Table 6. and graphically displayed in Figure 3.

Table 6: The effect of cementitious grouts on ITS at different test temperatures

| *Material* | *Indirect tensile strength at 28 days (kPa)* | | |
|---|---|---|---|
| | *5ºC* | *20ºC* | *60ºC* |
| HL/OPC-GM | 1027 | 957 | 219 |
| HL/SF-GM | 1152 | 1050 | 220 |
| HL/FA&SF-GM | 943 | 935 | 206 |

At a test temperature of 5ºC, the ITS values were approximately 110% higher than the ITS at 20ºC. Increasing the test temperature from 20ºC to 60ºC, reduced the ITS of the specimens by approximately 80%. It was clear that the mechanical properties of grouted macadams, similar to conventional bituminous mixtures, were highly dependent on the test temperature. The visco-elastic nature of the binder in the porous asphalt skeleton was clearly reflected in the performance of the grouted macadams.

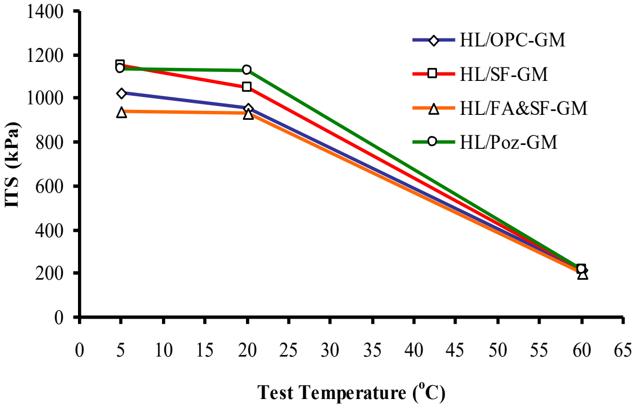

Figure 3: Effect of cementitious grout on the indirect tensile strength of grouted macadam at different test temperatures

Since all the results shown in Table 6. were of identical porous asphalt skeletons, it was clear that the properties of cementitious grouts also had a marked influence on the properties of grouted macadams. The relation between compressive strength of cementitious grouts and ITS of grouted macadam are presented in Table 7 and graphically displayed in Figure 4.

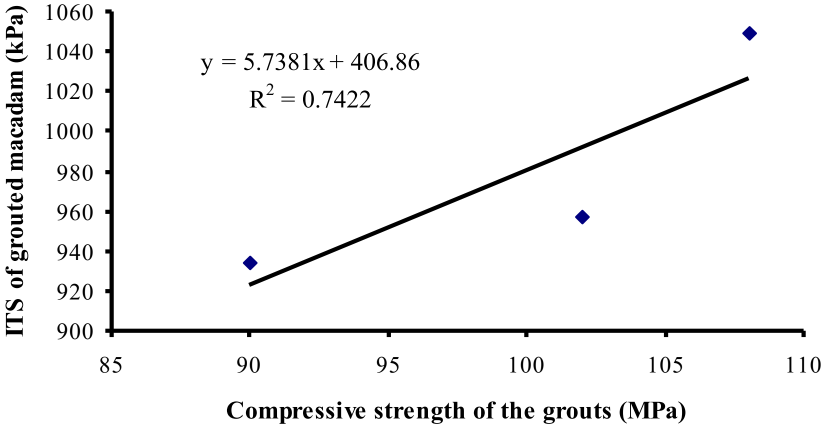

Figure 4: Relation between indirect tensile strength of grouted macadam and compressive strength of the grouts

In terms of ranking, it was clear that the strength of the hydrated cementitious grouts had a direct influence on the tensile strength of the respective grouted macadam.

Table 7**:** Relation between ITS and Compressive strength of cementitious grout

| *Material* | *Compressive strength of cementitious grouts (MPa)* | *ITS of grouted macadam (kPa)* |
|---|---|---|
| HL/OPC-GM | 102 | 957 |
| HL/SF-GM | 108 | 1050 |
| HL/FA&SF-GM | 90 | 935 |

## 4. CONCLUSSION

1. High workability cementitious grouts that can rapidly penetrate a porous asphalt skeleton by gravitational flow and provide adequate hydrated strength and performance properties were also successfully produced using combinations of readily available cementitious binders (including silica fume and fly ash) and chemical admixtures (superplasticizer).
2. The use of silica fume and fly ash were shown to enhance the porosity, permeability and shrinkage characteristics of the hydrated cementitious grouts
3. The indirect tensile strength of grouted macadams were greatly affected by the cementitious grout type, in general the higher the compressive strength of the cementitious grout, the higher the tensile properties of the hydrated grouted macadam.

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