Evaluation of Properties of Roller Compacted Concrete

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Abstract

The experimental and analytical behavior of various mixes of roller compacted concrete (RCC) using different materials is presented in this work. This work is divided into two groups of experiments.

In the first group a reference mix was prepared using local materials (cement, sand, aggregate). Mechanical and dynamic properties of reference mix with and without admixtures have been obtained. Also, this series includes a study of the various variables affecting the mechanical and dynamic properties of RCC.

In this work, the effect of cement content, water/cement W/C ratio and type of aggregate on the mechanical properties has been studied. The optimum mixes which have good properties obtained from the first group of study were used in the second group.

In this work, the effect of admixtures and type of admixtures (steel filings, metakaolin, fly ash, lime, rice husk and concrete wastes) on the mechanical properties has been studied.

The analysis of results showed that using steel filings improves the mechanical properties when replacing the sand by steel filings in (5, 10, 15 and 20) % by weight. The ultimate compressive strength at 7 and 28 days is higher by 13.2 and 24.7%, respectively, than the compressive strength using sand only. Partial cement replacement by mineral admixtures like metakaolin with (10, 20 and 30) %, lime with (4, 6, 8, 10, 20 and 30) %, fly ash with (10, 20 and 30) % and rice husk with (4 and 8) % decreases the strength and other properties at early age of 28 days by about 12.02% when using metakaolin by 20% and about 12.5% when using lime by 10 %.

1. Introduction

Roller compaction of concrete is a method of construction for dams; the few dams that have been completed to date have shown that the method promises considerable economies when compared with conventional concrete dam construction, and even when compared with earth dams **(Dunstan 1986).** Since completion in 1982 of Willow Creek dam, the first dam constructed in the United States entirely using roller compacted concrete (RCC), there has been a surge of interest and activity in the construction of dams by the new and promising technique in the USA **(Jackson 1986).**

Gravity dams built using the RCC construction method; afford economy and rapid placement techniques. Construction procedures associated with RCC require that particular attention be given in the layout and design to water tightness and seepage control, horizontal and transverse joints, facing elements and appurtenant structures **(EM 1110-2-2200).**

The use of RCC in dam construction and in other construction has some advantages such as the following **(ICOLD 2003)**:

1. More rapid construction.
2. Effective use of conventional equipment.
3. A reduced cost of construction because less cement is used in the mixture.
4. Pipe cooling is unnecessary because of the low temperature rise.

2. MIXES

During this work mixture proportioning, mechanical properties, mixing, placing, curing, protection, and design and construction of RCC are discussed. The effect of cement content, water cement ratio and type of aggregate on the mechanical and dynamic properties has been studied by using cylindrical specimens (150x300mm) and cubic specimens 150mm in size.
In order to select the mixture proportion for RCC, the design method recommended by **ACI committee 207.5R-1996** was adopted. The weights of the materials per cubic meter of RCC are:

Ordinary Cement	120	kg/m^3
Water	100	kg/m^3
Fine aggregate	630	kg/m^3
Coarse aggregate	1586	kg/m^3
Total	2436	kg/m^3

So this mix was considered as a preliminary mix to study the effect of variables. The cement content used ranged from 90 to 150 kg/m^3 and the W/C ratio from a 0.75 to 0.9. Therefore it was decided to use the mix which contained 150 kg/m^3 cement and water/cement ratio 0.8 as fixed mix proportions.

3. THE EXPERIMENTAL WORK

The aim of this experimental investigation is to study the behavior of RCC. As shown in schematic diagram of Fig. 1:

The aim of group 1 is to find the effect of cement content, water/cement ratio, water absorption of concrete specimens, type of aggregate (crushed and uncrushed), and density on the properties of RCC.

The optimum mix from group 1 which has good properties and fulfils the required characteristics of RCC was selected in order to be used in studying other properties in group 2 with the admixtures added.

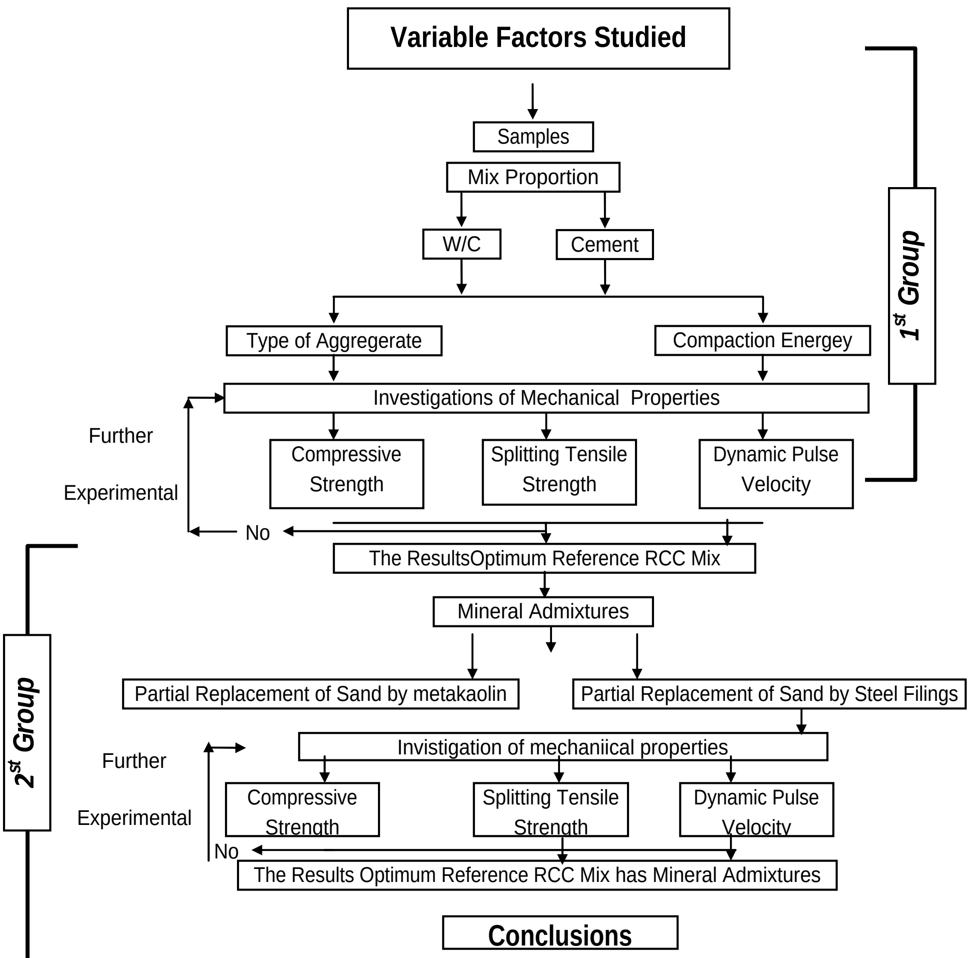

Figure 1 Testing Program of Study

Figure 1 Testing Program of Study

4. Results And Discussion

4.1 Effect of Cement Content Using Uncrushed Aggregate

Figures 2.a to 2.f show the effect of cement content on the mechanical and dynamic properties for uncrushed aggregate.

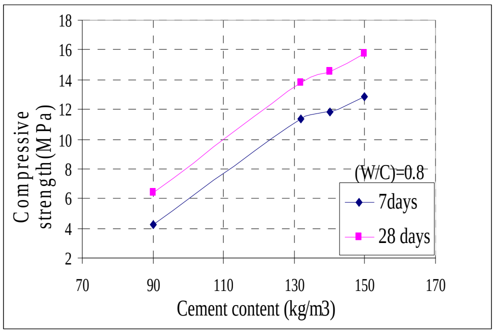

Figure 2.a Variation in compressive strength with cement content.

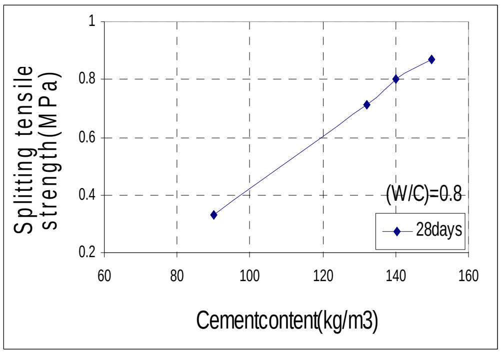

Figure 2.b Variation in splitting tensile strength with cement content.

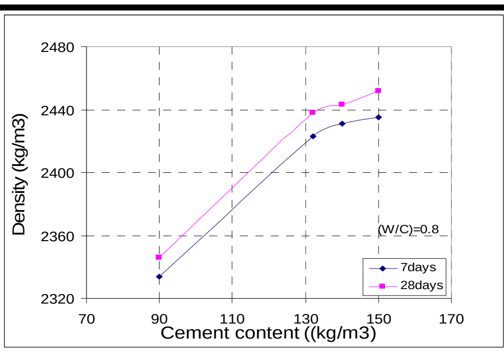

Figure 2.c Variation in density with cement content

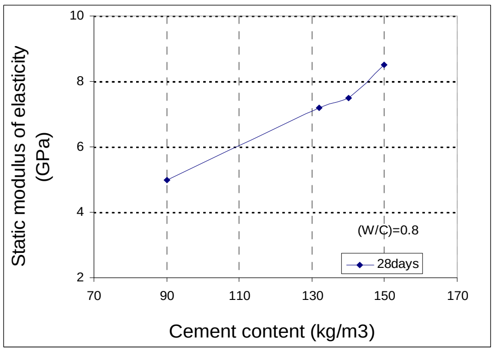

Figure 2.d Variation in static modulus of elasticity with cement content.

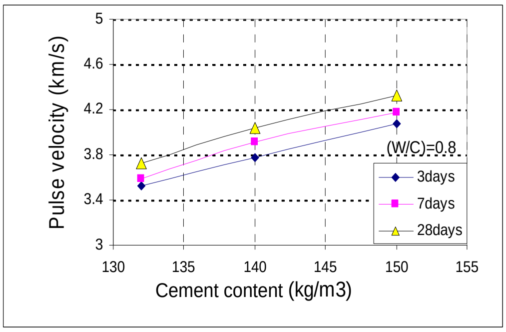

Figure 2.e Variation in pulse velocity with cement content

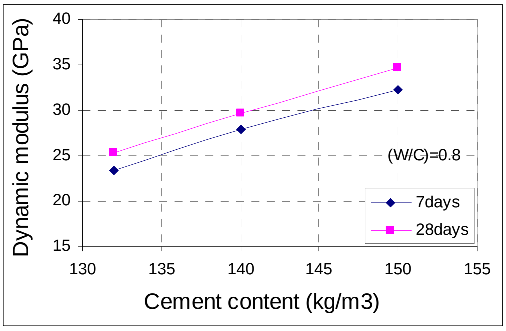

Figure 2.f Variation in dynamic modulus with cement content.

From the previous results and relationship of the cement content and compressive strength as shown in Fig. 2.a it clearly indicates that the compressive strength increases as the cement content increases. The rate of increase is relatively less when cement content is 132 kg/m^3 and more. It also indicates that at cement content is 90 kg/m^3, the compressive strength generally has small value, this due to the lack of cement paste that can fill the voids between aggregate **(Dunstan, 1986).**

The percentage increase in splitting tensile strength of concrete cylinders is above 95 % over that of 90 kg/m^3, while the average percentage increases for cement content from 132 to 150 kg/m^3 is about 21.8 %, Fig. 2.b.

Fig. 2.c shows the relationship between cement content and density of RCC specimens at 7 and 28 days age**.** The density increases invariably with the increase in cement content. Fig. 2.d shows an increase in static modulus of elasticity with increased cement content. This is because the increase in cement content will improve the strength and this improvement leads to increase the brittleness nature of the concrete that is the strain ability is reduced and the static modulus increases **(Ahmed, 2001).**

Fig. 2.e shows the relationship between the pulse velocity of RCC specimen for age 3, 7 and 28 days with cement content. It can be noticed that there is an increase in the pulse velocity as the cement content increases from 90 to 150 kg/m^3. The shape of relationship of pulse velocity versus cement content is similar to that of compressive strength as the cement content increases from 90 to 150 kg/m^3. The dynamic modulus increases as the cement content increases as shown in Fig. 2.f.

4.2 Using Different W/C Ratios with Uncrushed Aggregate

This section shows the effect of changing the value of W/C ratio with the mechanical and dynamic properties of RCC at different ages with the same cement content of 150 kg/m^3 as shown in Fig. 3.a to 3.f.

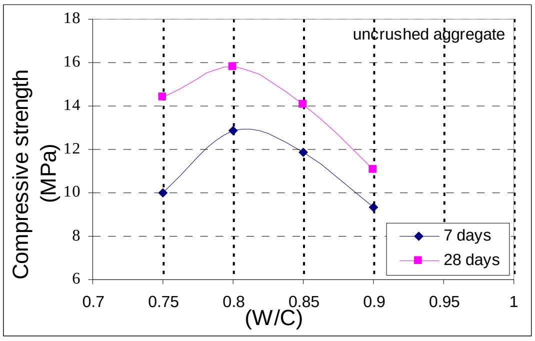

Figure 3.a Variation in compressive strength with W/C ratio

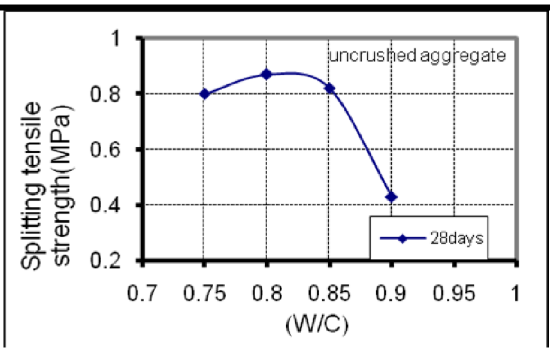

Figure 3.b Variation in splitting tensile strength with W/C **.**

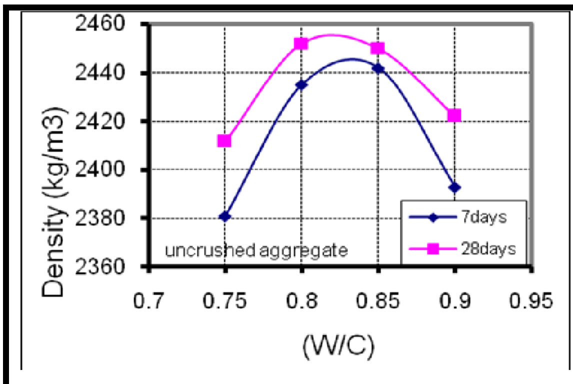

Figure 3.c Variation in density with W/C.

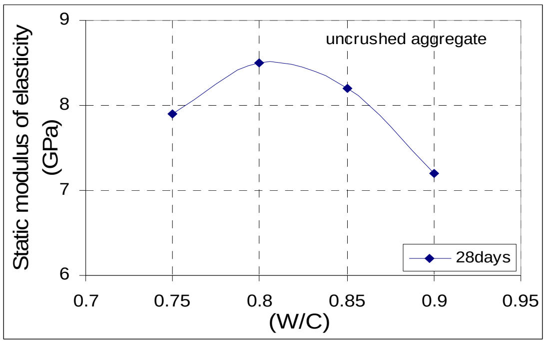

Figure 3.d Variation in Static modulus of elasticity with W/C.

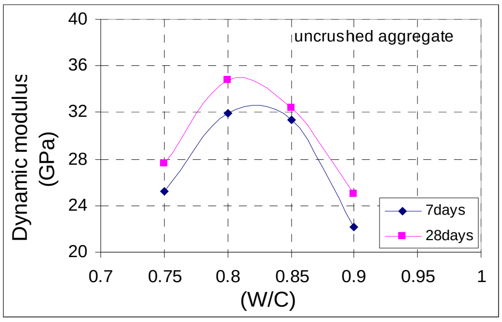

Figure 3.e Variation in pulse velocity with W/C ratio.

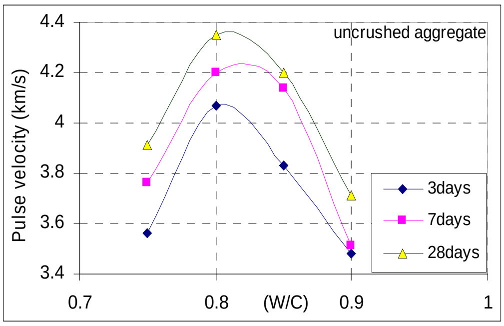

Figure 3.f Variation in W/C ratio with dynamic modulus.

Fig. 3.a shows that the compressive strength of RCC tends to increase with increased W/C ratio up to an optimum W/C ratio of 0.8. Further increase in the W/C ratio beyond the optimum causes a decrease in the compressive strength. The optimum W/C ratio invariably lies around 0.8.
Fig. 3.b and 3.c shows the relationship between the W/C ratio with density and with splitting tensile strength, of RCC at 28 days, respectively,; generally the behavior of them are similar to that of compressive strength.
The static modulus of elasticity with W/C ratio has the trend approximately similar to the behavior of compressive strength as shown in Fig.3.d.
The relationship between the W/C ratios with pulse velocity of RCC at different ages is shown in Fig. 3.e. it can be seen that the pulse velocity increases as the W/C ratio increases up to W/C= 0.8 after that the pulse velocity decreases.
It can be seen from Fig. 3.f that the trend relationship of dynamic modulus with W/C is similar to that of pulse velocity with W/C ratio.

4.3 Using Different W/C Ratios with Crushed Aggregate

This section deals with effect of crushed aggregate in the mixture of RCC. The mechanical and dynamic properties at different ages with W/C ratio are shown in Fig. 4.a to 4.f.

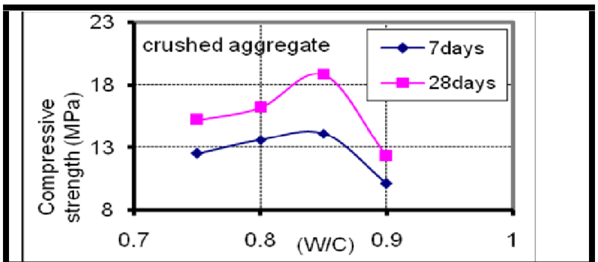

Figure 4.a Variation in compressive strength with W/C.

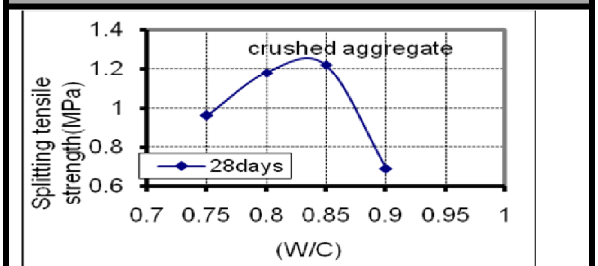

Figure 4.b Variation in W/C ratio with splitting tensile strength.

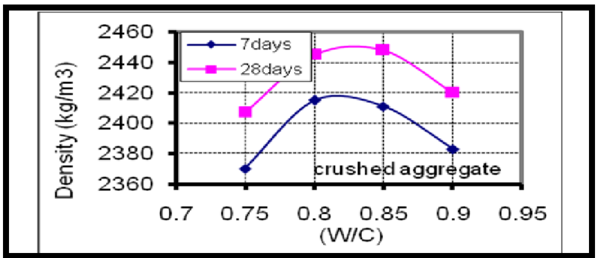

Figure 4.c Variation in W/C ratio with density.

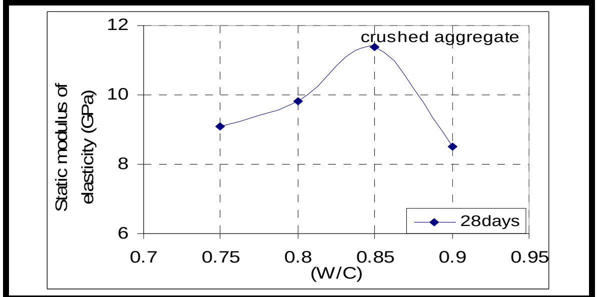

Figure 4.d Variation in static modulus of elasticity with W/C ratio. .

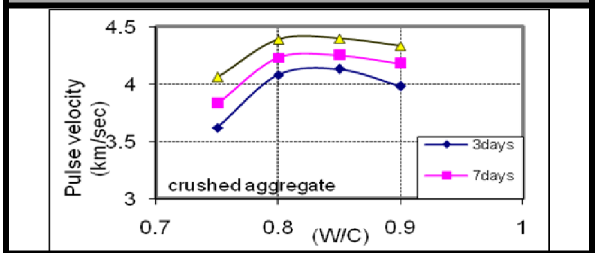

Figure 4.e Variation of pulse velocity with W/Cratio.

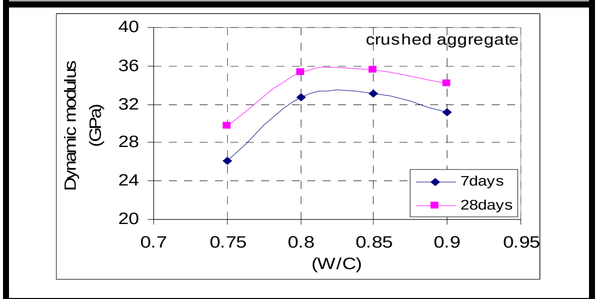

Figure 4.f Variation in dynamic modulus with W/C.

It can be noticed that the crushed aggregate needs more W/C ratio than the uncrushed aggregate; the best result was obtained when using W/C ratio of 0.85.
Fig. 4.a shows that the maximum compressive corresponding to optimum W/C ratio is higher by 9.00, 15.95 and 14.6% than the maximum compressive strength at 7, 28 and 60 days, respectively, compared with uncrushed aggregate.
It can be seen from the previous results in Fig. 4.b that the maximum splitting tensile strength is higher than the maximum splitting tensile strength of uncrushed aggregate by 28.6% at 28 days. The density increases up to reach a maximum value, and then decreases beyond the optimum W/C of 0.85,

this behavior is similar to the trend of density for uncrushed aggregate, (Fig. 4.c).

From Fig. 4.d it can be noticed that the maximum elastic modulus of RCC using crushed aggregate is higher than maximum elastic modulus obtained by using uncrushed aggregate by 24.77%.

Fig. 4.e shows that the maximum pulse velocity at optimum W/C of 0.85 at 3, 7 and 28 days are higher by 1.47, 1.8 and 1.14%, respectively, than that of the pulse velocity obtained by uncrushed aggregate.

The maximum dynamic modulus of RCC using crushed aggregate at 7 and 28 days is higher than that of uncrushed aggregate by 2.7 and 2.4%, respectively, (Fig. 4.f).

5. Effect Of Using Admixtures In Mixes On Properties Of Rcc

In this section the effect of using admixtures such as steel filings, metakaolin, lime and fly ash as an addition to RCC and the effect of using normal concrete waste on the mechanical properties and the dynamic properties at W/C of 0.83 will be discussed. Extra fines in the all in aggregate help to improve the workability in RCC mix that leads to increase the compressive strength, **(Haque, 1986).**

5.1 Effect of Adding Steel Filings Using Uncrushed Aggregate

The ultimate compressive strength of RCC using steel filings at 7 and 28 days is higher by 13.26 and 24.7 % respectively than the compressive strength at (steel filings/sand) ratio of 0%, as shown in Fig. 5.a.

The ultimate tensile strength at 28 days is higher by 43.4%, than the value at (steel filings/sand) of 0% as shown in Fig. 5.b. Fig. 5.c shows the results of density at 7 and 28 days when adding steel filings. It can be noticed, that the density increases until (steel filings/sand) ratio of 15 % is reached then density decreases with the increase in (steel filings/sand) ratio; density at ultimate (steel filings/sand) is higher than the value at (steel filings/sand) of 0 %.

The maximum static modulus of elasticity of RCC using the optimum ratio (15%) of (steel filings/sand) is higher by 31.7 % at 28 days than that without steel filings, as shown in Fig. 5.d.

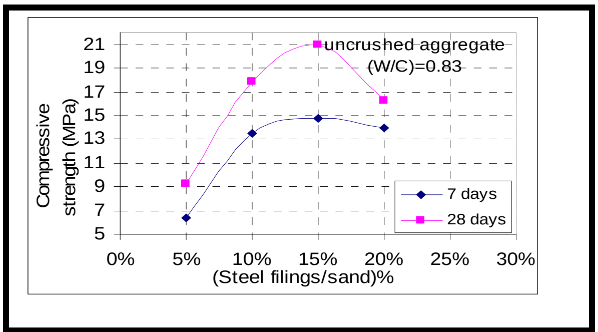

Figure 5.a Variation in compressive strength with (steel filings/sand) % ratio.

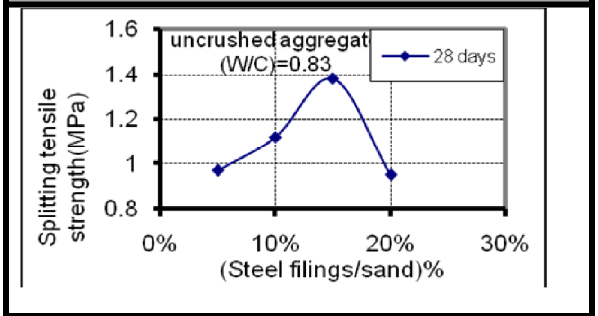

Figure 5.b Variation in splitting tensile strength with (steel filings/sand) % ratio

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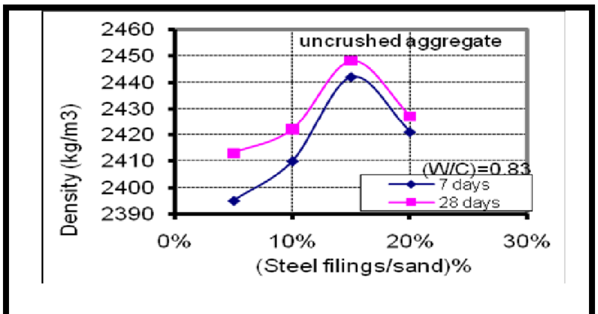

Figure 5.c Variation in density with (steel filings/sand) %.

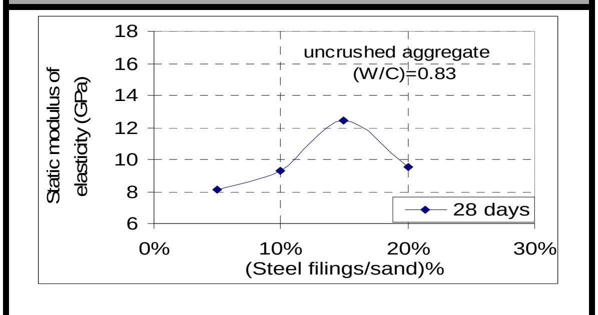

Figure 5.d Variation in static modulus with (steel filings/sand) %.

5.2 Effect of Adding Metakaolin Using Uncrushed Aggregate

From the experimental work it has been noticed that the using of pozzolana material in mixes does not cause an important increase in compressive strength at early ages of 7 days but the increase in compressive will be clearly worked beyond months. The long-term compressive strength (90 days in this work) of RCC using metakaolin is higher than that of ordinary concrete.

The reductions in compressive strength at (metakaolin/cement) of 20 % are 17.8%, 12.05% and 8.58% at 7, 28 and 60 days, respectively, with those of cement only. At early age one can notice a less rate of increase, after 60 days there is dramatic increase in compressive strength which can be noticed at 90 days, when the compressive strength at (metakaolin/cement) of 20% is higher by 5% than the compressive strength at (metakaolin/cement) in 0% at the age of 90 days. The percentage increase of compressive strength of RCC mix using 20% metakaolin at 90 days is greater by 40.0 % over that of 60 days while the average percentage increase for the age from 7 to 60 days is about 25.7 %, as in Fig. 6.a.

The reduction in splitting tensile strength of (metakaolin/cement) ratio of 20% is 1.2% at 28 days in comparison with the splitting tensile strength of using (metakaolin/cement) ratio of 0%, as shown in Fig. 6.b.

It can be seen from fig. 6.c that the relationship of density with (metakaolin/cement) content has the same trend as the compressive strength. Density is increasing until it reaches an optimum value of (metakaolin/cement) ratio of 20%.

Generally the static modulus of elasticity increases with increasing the curing age, and the increase is higher at lately age beyond 28 days. The static modulus of elasticity is less at (metakaolin/cement) ratio of 20% at 28 days by 3.65% in comparison with that of using cement only, as shown in Fig. 6.d.

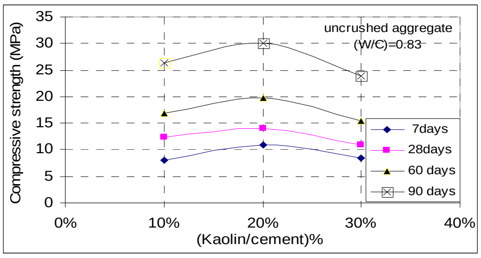

Figure 6.a Variation in compressive strength with (metakaolin/cement) %.

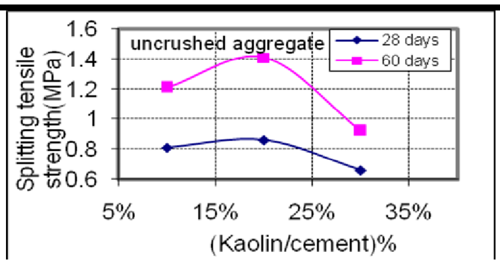

Figure 6.b Variation in splitting tensile strength with (metakaolin/cement) %.

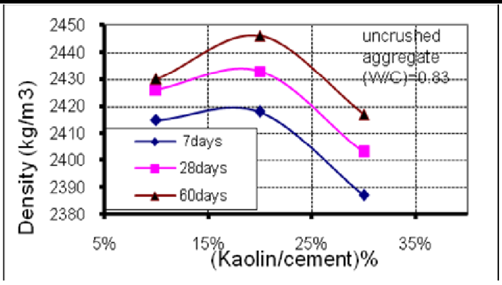

Figure 6.c Variation in density with (metakaolin/cement)%.

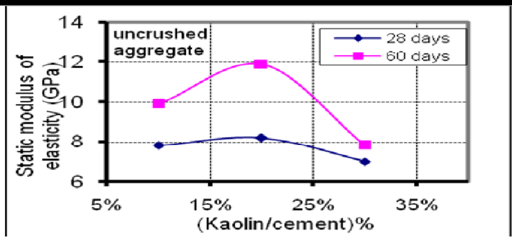

Figure 6.d Variation in static modulus with (metakaolin/cement) %.

More series of testing have been performed to evaluate the influence of other admixtures. The influence of these admixtures on the properties of RCC could be summarized below:

1. Lime: When mixed with cement the silica combines with the free lime (Ca $(OH)_2$) released during the hydration of the cement, to form Calcium Silicate **(Orchard 1979).**

Maximum compressive strength at (lime /cement) ratio of 6% at 28 days is less by 1.02% than that of (lime /cement) ratio of 0%.

2. Fly Ash: The reduction in compressive strength at 7 days when adding **10** % fly ash is about **70** % in comparison with that of (fly ash/cement) ratio of **0**%.

3. Concrete Wastes: The compressive strength by using concrete wastes is lower than that of normal concrete by **11.06** and **8.9** % for 7 and 28 days, respectively

5.3 Effect of Adding Steel Filings on RCC Using Crushed Aggregate

Using crushed aggregate needs more W/C ratio than uncrushed; the best result was when using W/C ratio of 0.85.

Using crushed aggregate gives better results for all mechanical and dynamic properties except the density of RCC.

The maximum compressive strength at (steel filings/sand) ratio of 15% is higher by 7.1, 16.6 and 9.3 % at 7, 28 and 60 days respectively for the compressive strength than those of using sand only.

5.4 Effect of Adding Metakaolin Using Crushed Aggregate

Using crushed aggregate gives better than results for all mechanical and dynamic properties of RCC except the density.

The maximum compressive strength of RCC at (metakaolin/cement) ratio of 20% is higher than the maximum strength for uncrushed aggregate by 14.5 and 7.3% at 28 and 60 days respectively. Also, it is clearly seen that the ultimate compressive strength of RCC mix using crushed aggregate at (metakaolin/cement) ratio of 20% is less than those at (metakaolin/cement) ratio of 0% by 13.9 and 22.9% at 28 and 60 days, respectively

6. Conclusions

- Experimental work has been made to study the factors affecting the behavior of RCC dam.

- Using crushed aggregate increases the interlocking between particles of aggregate, and gives better mechanical properties than with uncrushed aggregate. Crushed aggregate needs more W/C ratio. The magnitude of density of RCC decreases when using crushed aggregate, since the rounded particles decrease the voids.

- Compressive strength and other mechanical properties increase with the addition of steel filings as a percentage of sand content in comparison with the reference mix of RCC. Strength increases until the (steel filings/sand) ratio reached an optimum value of 15%, and it is higher by 24.7% than the strength of the reference mix without steel filings.

- Partial cement replacement by mineral admixture causes reduction in compressive strength at early age compared with the reference mix. Good results can be obtained after three months and more. The compressive strength at optimum value of (metakaolin/cement) of 20% is higher by 5% than the strength of (metakaolin/cement) of 0% at the age of 90 days. In general the specimens that contain crushed aggregate possess better mechanical properties than those with uncrushed aggregate except the increase in density.

- Using mineral admixtures need more W/C ratio in comparison with reference mix. The optimum W/C when using mineral admixtures reaches 0.83 in uncrushed aggregate mixes.

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