International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 04 Issue: 11 | Nov -2017 www.irjet.net p-ISSN: 2395-0072

FRACTURE AND STRENGTH STUDIES ON CONCRETE WITH DIFFERENT TYPES OF COARSE AGGREGATES

Dr S.Siva Murthy Reddy[1], Bitta Ramakrishna[2]

[1]Professor Department of Civil Engineering, Pondicherry Engineering College, Puducherry, India.
[2]Research scholar Department of Civil Engineering, Pondicherry Engineering College, Puducherry, India.

***

ABSTRACT - Concrete, a multiphase composite material consists of cement matrix, aggregate and the interface between the cement paste and aggregate. Approximately 65 to 80 percent of the concrete volume is occupied by the aggregate. For a given mix proportion, concrete may produce different strength when the coarse aggregates are varied. The possible causes of the strength variation in concrete are the surface texture, shape, strength, mineralogical composition and elastic properties of the coarse aggregate. Six types of coarse aggregates namely Granite, Dolerite, Quartzite, Limestone, Dolomitic limestone and River gravel were used in concrete making. Three concrete mixes will be designed for a characteristic compressive strength of 30, 50 and 70 MPa at 28-day with a w/c ratio of 0.5, 0.35 and 0.3 respectively. The type of cement and fine aggregate used in the mixes were not varied. The hardened mechanical and fracture properties of concrete such as its compressive strength, splitting tensile strength, elastic modulus, fracture energy and characteristic length were measured. In all the concrete grades, Granite and Dolerite aggregate concretes yielded higher compressive strength and fracture energy. The carbonate aggregate concrete yield good results when compared to River Gravel aggregate concrete. River Gravel aggregate concrete produced lower results in all concrete grades because of its smooth texture and round shape.

Keywords: Aggregate type, normal and high strength concrete, fracture energy, compressive strength.

1. INTRODUCTION

1.1 GENERAL

In the field of structural design, the traditional goals of engineers were the design of a safe and economical structure. Nowadays, there is a growing concern for sustainability, which leads to a change in the accounting of resource consumption. Through years of practice and experience, concrete has proven to be the most suitable material for building construction. The use of concrete, especially high strength concrete (HSC) as a primary structural material in structures such as tall buildings, submerged structures, bridges, dams, liquid and gas containment structure has increased in the recent past. At present, concrete of strength greater than 100 MPa have been employed in many new high-rise reinforced concrete buildings which is challenging as of quality, strength, durability is required at an economical cost. These issues can be solved by adopting new construction technology and by proper selection of materials used to make concrete.

The importance of using the right type and quality of the aggregates cannot be exaggerated. The fine and coarse aggregates generally occupy 65 to 75 percent of the concrete volume and strongly influence the fresh and hardened properties of the concrete, mixture proportions, and economy. Less effort has been given to understanding the concrete fracture properties, especially in case of high strength concrete where the coarse aggregate plays an important role which influences the fracture behavior of concrete to a great extent. Therefore, detailed information about concrete fracture properties is required along with the strength to better quantify crack propagation of concrete while designing the concrete structures. For a normal strength concrete, fracture energy depends primarily on the water-to-cement ratio, maximum aggregate size and the age of the concrete. In case of high strength concrete, the fracture energy is mainly influenced by the mineralogical nature of aggregate, the geometry of the aggregate, volume of the aggregate and water-to-cement ratio.

This report is aimed to provide a better understanding of the effects of aggregate type on the strength and fracture characteristics of normal and high strength concretes. Special consideration has been given to fracture energy and characteristic length of concrete.

2. LITERATURE REVIEW

2.1 Compressive Strength of Concrete

Concrete is the most commonly used structural materials along with steel. The strength of the concrete is of quintessence which is the maximum load that the concrete can carry. The compressive strength of the concrete typically depends on aggregate strength, cement matrix strength and the strength of the interface between the cement and the aggregates. Mechanical interlocking between the aggregate and cement paste has a significant role in the bond strength. The surface texture of the coarse aggregate is partly responsible for the bond between the coarse aggregate and matrix (Kaplan, 1959). The concrete made with crushed stone achieved a higher compressive strength than the uncrushed aggregate. Also entirely smooth aggregates lowered the strength of the concrete by 10 percent than the roughened aggregate (Neville, 1981). Most of the researches revealed that the river gravel produced lower compressive strength on comparing with other aggregates. The smooth surface texture of the aggregate made the interlocking between the aggregate and binder weak, resulted in lower compressive strength (Aitcin et al, 1990; Cetin et al, 1998; Aydin et al, 2010 and Abdullahi, 2012). Apart from the surface texture of gravel, surface cleanliness also matters. The unwashed gravel shows a reduction in the strength of the concrete of around 35 percent as its surface was coated with clay, silt and humus (Aginam et al, 2013). Granite with a smooth surface texture also yielded lower compressive strength even though the aggregate strength is very high (Aydin et al, 2010). This effect depends on water-to-cement ratio and is more pronounced at lower water-to-cement ratio (Neville, 1981).

Apart from mechanical interlocking, chemical interaction between the cement matrix and aggregate results in strong bond. Chemical bond exists in case of concrete made with limestone, dolomite and siliceous aggregates (Neville, 1990). Limestone produced quite higher compressive strength though it appears to be weaker aggregate. This is because of the possible chemical reaction between the calcite mineral and cement paste which made the interfacial zone stronger (Aitcin et al, 1990 and Cetin et al, 1998).

The strength of the concrete improved with increasing strength of the coarse aggregate. However, for normal strength concrete the effect of the aggregate strength on the compressive strength of the concrete is not significant. Aggregate in comparison with concrete, had relatively higher strength and its potential strength was not fully utilized in normal strength concrete (Wu et al, 2001). Basalt (high strength aggregate) and limestone (relatively low strength aggregate) produced similar compressive strength for normal and medium strength concrete. However in case of high strength concrete, basalt concrete produces significantly greater strength and about 25 percent higher than limestone concrete (Kaplan, 1959; Darwin et al, 2001 and Sengul et al, 2002). Similarly, crushed quartzite concrete yields 10-20 percent higher compressive strength than the marble aggregate concrete (Chen et al, 2004). In reactive powder concrete, sintered bauxite concrete produced a higher strength of 200 MPa as the aggregate poses the highest aggregate strength and rougher texture than limestone, granite, basalt and gravel (Aydin et al, 2010).

In general, the aggregate properties affecting the compressive strength of concrete are shape, surface texture and modulus of elasticity. These properties have a significant effect on high strength concrete rather in normal strength concrete (Kaplan, 1959). In reactive power concrete, limestone with a rough surface texture and low strength and granite with quite smooth surface texture and high strength shows a compressive strength above 180 MPa whereas quartz aggregate concrete had the lowest strength of 170 MPa as it has a very smooth surface which resulted in poor interlocking between the aggregates and cement paste (Aydin et al, 2010).

Aggregates with higher elastic modulus than cement matrix causes the critical concentration of principle stresses and subsequently micro-cracking at the bond interfaces, reducing the compressive strength of the concrete (Baalbaki 1991). In normal strength concrete, quartzite aggregate concrete exhibited the high elastic modulus, but the lowest compressive strength, because the relatively high stiffness of the aggregate, which improved the concrete rigidity, also caused stress concentrations at the interface at high stress levels. Also sandstone with a relatively low elastic modulus exhibited the lowest elastic modulus, but the highest compressive strength of the concrete (Baalbaki, 1991). In normal strength concrete, Triassic limestone, which is a soft aggregate, exhibits higher compressive strength as the Young's modulus of the aggregate is close to that of cement matrix which lowers the stress concentrations at the aggregate-cement interface. Whereas Devonian limestone, basalt and sandstone aggregate concrete whose aggregate's elastic modulus are relatively higher than cement matrix had a negative effect on the compressive strength of normal and medium strength concrete (Sengul et al, 2002).

For all types of aggregates, increasing the coarse aggregate content increases the compressive strength of the concrete, but beyond 40 percent did not appear to assistance the compressive strength, especially in case of dolomitic limestone, trap rock and gravel (Cetin et al, 1998).

Depending on the aggregate type, on an average difference of 29 percent in compressive strength and 40 percent in flexural strength of concrete were obtained (Kaplan, 1959).

Effect of silica fume plays a positive role in the compressive strength of the concrete (Tasdemir et al, 1999 and Chang et al, 1998). The addition of 15 percent silica fume by volume of cement resulted in higher compressive strength of concrete when compared to 10 percent and 5 percent dosage. But such high percent addition of silica fume may result in increased shrinkage and hence generally limited to 10 percent dosage. The average improvement in the compressive strength of limestone, dolomite, and granite due to the addition of silica fume is in the range of 12 to 17 percent (Almusallam et al, 20

2.2 Splitting Tensile Strength of Concrete

The tensile strength of the concrete is more sensitive to difference in aggregate surface texture. The aggregate-cement bond strength seems to control the tensile strength of the concrete. Splitting tensile strength of concrete is influenced by the splitting tensile strength of aggregates to a small extent (Hassanzadeh, 1998 and Wu et al, 2001). Effect of silica fume has a positive effect on tensile strength of the concrete. The highest splitting tensile strength of concrete was obtained in 15 percent Addition of silica fume followed by 10 percent and 5 percent. The increased splitting tensile strength of concrete may be because of the reaction between the calcium hydroxide from the hydration process of cement and silica fume (Almusallam et al, 2004). The tensile strength of basalt concrete is higher than limestone and sandstone as a result of strong interface due to the inclusion of silica fume. As a result, the concrete exhibits transgranular type of failure in high strength concrete. But in normal strength concrete, basalt yielded lower value resulting in the intergranular type of fracture, probably due to mismatch between the weak matrix and strong aggregate (Sengul et al, 2002).

2.3 Elastic Modulus of Concrete

The nature of coarse aggregate significantly affects the modulus of elasticity of concrete, especially high strength concrete. This influence was attributed to the highly dense paste structure and paste-aggregate bond that causes the concrete to behave like a composite material, particularly in case of low water-to-cement ratio and high cement content (Aitcin et al, 1990; Baalbaki et al, 1991 and Nevile 1997).

In general, concrete with stiffer aggregates produces higher elastic modulus. The elastic modulus of the concrete appears to be independent of aggregate size at a given aggregate content. This is because the concrete is loaded up to 40 percent of the ultimate load so that bond strength between the Aggregate and cement is no longer a limiting parameter (Alexander et al, 1995; Neville 1997; Cetin et al, 1998 and Sengul et al, 2002). There exists a relationship between elastic modulus of aggregate and concrete. Aggregate with higher elastic modulus produces higher modulus of elasticity of concrete for given a water-to-cement ratio (Neville, 1997). The variation in the modulus of elasticity of the concrete with different types of coarse aggregate is less pronounced in high strength concrete. This is because of the better interfacial zone between the cement paste and aggregate at low water-to-cement ratio (Sengul et al, 2012). Diabase aggregate has an elastic modulus of 105 GPA, which is far higher than granite, gneiss and quartzite, resulted in higher elastic modulus of concrete (Hassanzadeh, 1998). Next to that, quartzite concrete produced higher elastic modulus, the reason may be that Young's modulus of quartzite aggregate is 30 to 50 percent higher than other aggregate (Wu 2001). In each concrete class, sandstone concrete has the lowest elastic modulus as it has the least elastic modulus value (Baalbaki et al, 1991 and Sengul et al, 2002).

Apart from stiffness and surface texture of coarse aggregate, researches showed that chemical bond between the aggregate and the cement paste plays a significant role. A possible chemical interaction between the calcite in limestone and calcium hydroxide in hydrated cement paste makes the transition zone stronger and resulted in higher elastic modulus value in the concrete with limestone aggregates. Also, granite aggregate which appeared to be hard and strong, but produced lower elastic modulus and strength. Mineralogical examination showed the presence of laumontite, a zeolite mineral that is known to be unstable in moist environment, resulted in transgranular kind of failure (Aitcin et al, 1990).

2.4 THE FRACTURE PROPERTIES

Fracture energy (Gf), is the energy dissipated per unit area during the formation of a crack and the length of the fracture zone is called as Characteristic length (lch), a pure material property which determines how sensitive a material is to crack propagation (Hillerborg 1985).

Fracture energy and characteristic length are influenced by the quality of aggregate. In general, stronger aggregates produces a higher value of fracture energy than the weaker aggregates. Stronger aggregate requires higher energy to crack in high strength concrete and hence resulted in higher fracture energy. Fracture of basalt concrete is twice that of limestone concrete for a constant water-to-cementitious ratio and age (Darwin et al, 2001). The reason is the difference of the crack paths during the fracture process. A strong aggregate material with high Young's modulus and a good bond between aggregate and paste probably a cause of more complex crack formation which resulted in higher fracture energy (Peterssson, 1980). Weaker aggregates such as shale, gravel and limestone produces lower fracture energy on comparing with stronger aggregates like basalt, granite and quartzite (Kan, 1995).

In normal strength concrete, with both weak and strong type of aggregates, the fracture surface was torturous and the cracks run around the aggregates. The basalt concrete had virtually no fractures through the course aggregate while the limestone concrete showed evidence of some transgranular fracture (Aitcin et al, 1990, Darwin et al, 2001). High strength concrete, the crack passes through the aggregate and resulted in transgranular type of failure. The medium strength concrete had a composite fracture surface, those observed in normal and high strength concrete (Darwin et al, 2001).

Fracture energy increases with increasing age of the concrete and also with increasing fraction of aggregate. The closer the aggregate particles are packed, the more complex is the crack pattern and larger is the crack surface and fracture energy (Petersson, 1980). Also Gf increases with increasing aggregate size as the surface of the aggregate became rough and complex (Chen et al, 2004). But for a given type of aggregate fracture energy decreases when the water-to-cement ratio increases, at least when the water-to-cement ratio exceeds 0.4 (Kan, 1995). For a given water-to-cement ratio, fracture energy varies when different types of coarse aggregates are used. Fracture energy increases with increasing compressive strength of the concrete for any given type of coarse aggregate type (Wu et al, 2001, Darwin et al, 2001 and Ruiz et al, 2010). But the characteristic length decreases with increasing compressive strength of concrete for a given aggregate type (Petersson, 1980; Hassanzadeh, 1998 and Chen et al, 2004).

Fracture energy of the concrete increases with increasing fracture energy of the coarse aggregate (Wu et al, 2001). Basalt, bauxite and granite reactive powder concrete showed higher fracture energy as their fracture energy of the aggregates were higher. Whereas quartz and limestone aggregated reactive powder concrete showed poor performance compared to the other aggregate. This was because quartz was the smoothest surface and limestone had the lowest fracture energy (Aydin et al, 2010).

Addition of silica fume has a negative impact on fracture energy of the concrete, the cracks usually traversed through the aggregate, transgranular type of fracture and brittle in nature. However, in graved aggregate concretes with silica fume, the crack bas not traversed the aggregate due to its rounded shape and smooth surface (Chan et al, 1998 and Tasdemir et al, 1999). But silica fume has a positive effect on concrete made of quartzite (Hassanzadeh, 1998).

2.5 SUMMARY

The following information summarizes the findings of previous studies on the effects of aggregate type and it Characteristics of normal, medium, and high-strength concretes.

2.5.1 Mechanical Properties

1. In general, the type of coarse aggregate has a little effect on the mechanical properties of normal strength concrete (NSC). For NSC, bond cracks exist in cement phase to a considerable extent before the concrete subjected to any external load. Under load, these cracks extend and interconnect; at ultimate load the whole structure is completely disrupted. Aggregate in comparison with concrete, had relatively higher strength and its potential strength was not fully utilized in NSC.

2. In case of high strength concrete (HSC), stronger aggregates produce greater concrete strengths. From the above literatures, it is obvious that the strength of the concrete is predominantly rely on the characteristics of the coarse aggregate used. Some researchers concluded that the variation in the mineralogical composition can produce weaker or stronger mechanical properties of concrete especially in HSC.

3. Also the aggregate-paste bond is strongly influenced by the shape, surface texture and the nature of the aggregate. Proper selection may result in improved strength up to 40%.

2.5.2 Fracture Properties

1. The above discussed literatures showed there exist a relationship between the fracture properties of concrete and aggregate, for various w/c ratios and different types of coarse aggregates.

2. In NSC, coarse aggregate acts as crack arrestors during the fracture process and the cracks propagate around the aggregate whereas in HSC the fracture takes place through the coarse aggregate. Therefore, in HSC, the fracture energy of aggregate has a greater influence on the fracture energy of concrete than is the case in NSC.

3. The fracture energy of concrete increases with increasing fracture energy of aggregates, especially in basalt, granite and quartzite aggregate. Also the fracture energy increases with increase in the compressive strength of concrete for any given coarse aggregate type.

4. The characteristic fracture length of concrete decrease with an increasing concrete strength which indicates that the concrete will be more brittle in HSC.

5. Addition of silica fume has a negative effect on fracture energy for a given type of concrete class. Silica fume reacts with calcium hydroxide forming the interface zone stronger. Thus the cracks traversed through the aggregate and reduce the fracture energy

3. EXPERIMENTAL INVESTIGATION

3.1 MATERIALS

In this chapter, the selected materials, mechanical properties of coarse aggregates and mix proportions of three different grade concrete are presented

a) Cement

In this project, 53-grade ordinary Portland cement was used as the binder. The cement was tested for its physical properties in accordance with IS: 4031-1988 and the results of the tests are reported in Table 1 which was found to be satisfactory as per IS: 12269 (Part 2) -1987.

Table 1: Physical Properties of Cement

Sl. No.	Properties of Cement	Results
1	Specific gravity	3.14
2	Initial setting time (min)	55
3	Final setting time (min)	152
4	Consistency (%)	34

b) Fine

Properties of Fine Aggregate

Locally available river sand passing through 4.75 mm was used in this present study as fine aggregate. The properties of fine aggregate were tested in accordance with IS: 2836-1963 and IS: 383-1970. The results are given in Table 2 which was found to be satisfactory for making of concrete.

Table 2: Physical Aggregate

Sl. No.	Properties of Cement	Results
1	Specific gravity	2.64
2	Fineness Modulus	3.48
3	Density (kg/m3)	1604
4	Water Absorption (%)	1.5

c) Water

Ordinary portable water is used for the entire experiments, studies and also for curing of specimens in accordance with IS: 456-2000.

d) Coarse Aggregate

In this present study, six types of coarse aggregates are used. Of which, Granite, Dolerite, Dolomitic limestone, Limestone and Quartzite were obtained from Cudddapah district of Andhra Pradesh and River Gravel was obtained from Ossuteri of Puducherry. The physical and mechanical properties of aggregates of coarse aggregates are studied in accordance with IS:2386-1963 and the results are presented in Table 3.

Table 3: Mechanical Characteristics of Coarse Aggregates

Property	**Granite**	**Dolerite**	**Dolomite**	**Limestone**	**Quartzite**	**Gravel**
Bulk density (kg/m3)	1440	1580	1485	1420	1500	1610
Specific Gravity	2.60	2.88	2.79	2.72	2.57	2.51
% of voids	38.46	39.93	38.97	37.70	37.59	35.85
% of solids	61.54	60.07	61.03	62.30	62.41	64.15
Angularity Number	5.46	6.93	5.97	4.70	4.59	3.47
Impact value (%)	17.76	10.44	15.285	20.29	23.94	22.04
Crushing Value (%)	21.78	14.04	19.64	24.36	23.45	26.97
Elongation Index (%)	34.89	42.25	41.27	30.31	41.93	36.75
Flakiness Index (%)	9.48	26.87	18.69	21.64	18.62	20.14
Water Absorption (%)	0.50	0.75	1.00	0.50	0.50	0.60

3.2 MIX PROPORTIONING

Concrete mixes were designed to have a target compressive strength of 30, 50 and 70 MPa at 28-day with a water-to-cement ratio of 0.5, 0.35 and 0.3 respectively. The type of cement and fine aggregate were same for all mixes. The aggregates are designated as D, G, Q, DL, LS and R.G for Dolerite, Granite, Quartzite, Dolomitic Limestone, Limestone and River Gravel respectively. The mix proportions are presented in the Table 4.

Table 4: Mix Proportion of Three Concrete Mixes

Mix Code	**Cement (Kg/m3)**	**w/c**	**Coarse Aggregate (Kg/m3)**	**Fine Aggregate (Kg/m3)**	**Water (l)**	**Super Plasticizers (l)**	**Silica Fume (Kg/m3)**
G 32	360	0.5	1138	711	180	-	-
D 30	360	0.5	1261	711	180	-	-
Q 30	360	0.5	1125	711	180	-	-
DL 30	360	0.5	1221	711	180	-	-
LS 30	360	0.5	1191	711	180	-	-
RG 30	360	0.5	1099	711	180	-	-
G 50	480	0.35	881	847	168	2.4	-
D 50	480	0.35	976	847	168	2.4	-
Q 50	480	0.35	871	847	168	2.4	-
DL 50	480	0.35	922	847	168	2.4	-
LS 50	480	0.35	946	847	168	2.4	-

RG 50	480	0.35	848	847	168	2.4	-
G 70	500	0.3	868	858	160	2.5	35
D 70	500	0.3	962	858	160	2.5	35
Q 70	500	0.3	858	858	160	2.5	35
DL70	500	0.3	908	858	160	2.5	35
LS 70	500	0.3	932	858	160	2.5	35
RG 70	500	0.3	862	858	160	2.5	35

3.3 CASTING OF SPECIMENS

Prior to batching, the aggregate moisture content was obtained. The water and aggregate weights were then corrected. The concrete was hand mixed and before mixing, the mixer pan was wiped down with water to ensure that all of the mixing water was used to hydrate the cementitious material. All dry materials were placed in the pan and mixed uniformly. For HSC, the water reducer was used to obtain the workability. The silica fume was added at 7.5 percent of the mass of cementitious material for M70 grade concrete mix to attain the required compressive strength. After mixing, cube and prisms were cast to test the compressive strength and fracture energy. The specimens were removed from the mould after 24 hours. The demolded specimens were placed in water for curing until the age of testing. The size and number of specimens for compressive strength and fracture energy testing were presented in Table 5.

Table 5: Specimen Details

Test	Specimen	Specimen Size (mm)	No. of Concrete Mixes	No. of Specimen
Compression Test	Cube	100x100x100	18	54
Fracture Energy Test	Prism	500x100x100	18	54
Splitting Tensile Test	Cylinder	100ϕx200	18	54
Modulus of Elasticity	Cylinder	150ϕx300	18	54

4. RESULTS AND DISCUSSION

4.1 PROPERTIES OF CONCRETE

The properties of fresh and hardened concrete such as workability, unit weight, compressive strength, split tensile strength and elastic modulus are given in Table 6.

Table 6: Mechanical Properties of Concrete

Mix Code	Mean Unit Weight (kg/m3)	Slump (mm)	Mean Compressive Strength (MPa)	Mean Split Tensile Strength (MPa)	Mean Elastic Modulus (GPa)
D 30	2561	60	38.10	2.92	28.2
DL 30	2510	80	41.18	3.13	26.9
G 30	2400	75	37.63	2.81	26.5
L 30	2446	60	35.06	2.98	27.4
Q 30	2437	70	38.69	2.67	26.3
RG 30	2396	120	34.09	2.76	26.2
D 50	2574	54	60.12	3.20	34.1
DL 50	2504	65	55.38	3.00	30.9
G 50	2431	60	56.64	3.55	33.7
L 50	2426	58	55.29	3.90	33.4
Q 50	2443	65	54.85	3.53	32.2
RG 50	2405	84	51.80	3.53	29.5
D 70	2587	37	75.85	4.51	40.1

DL 70	2529	56	70.57	3.82	35.2
G 70	2472	45	74.78	4.32	37.5
L 70	2432	40	71.56	4.03	37.8
Q 70	2438	50	66.34	3.70	35.7
RG 70	2399	70	63.06	3.75	35.1

4.2 WORKABILITY OF CONCRETE

The surface texture and shape of the aggregates plays a significant role on the workability of concrete. The surface texture of aggregates such as Dolerite, Granite and Quartzite were rough and angular whereas Dolomitic limestone, Limestone and River Gravel were smooth. The slump of the concrete varies from 35 to 120 mm. In all the concrete mixes, the concrete mix containing River Gravel shows maximum slump followed by Dolomitic Limestone and Quartzite (Fig 1). The high slump value of River Gravel aggregate concrete is mainly due to its shape and texture and almost 40-50 % higher than other aggregate. The concrete mix with Dolerite aggregate causes reduction in slump because of its rough texture and high flakine

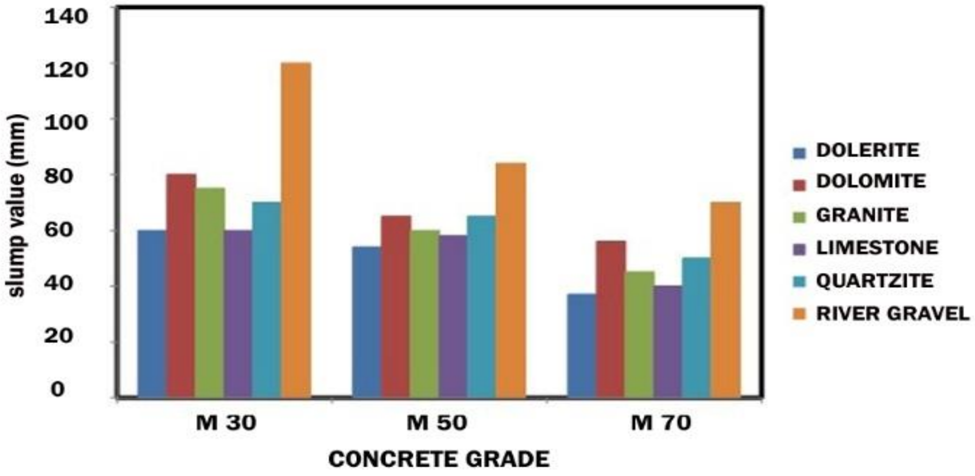

Fig. 1: Effect of Coarse Aggregate type on Slump with various Concrete Grades

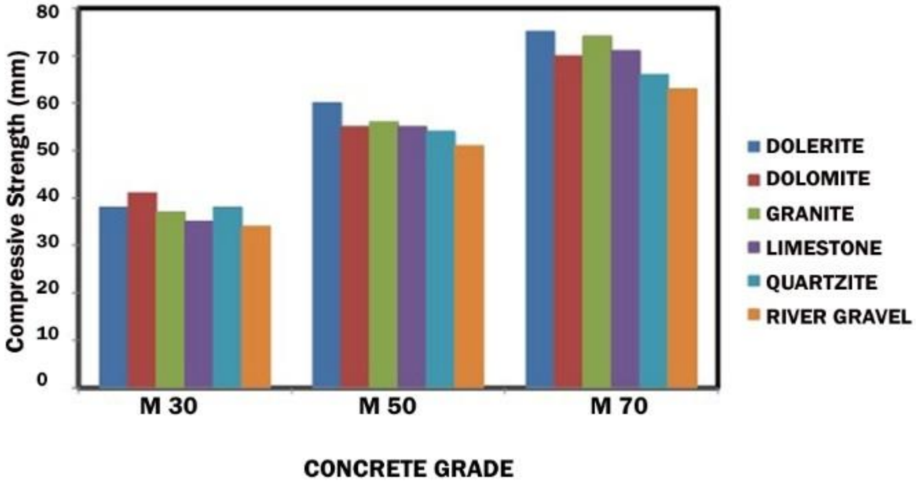

Fig. 2: Effect of Coarse aggregate type on Compressive Strength of various Concrete Grads

At HSC, the use of low w/c ratio and admixture made the cement matrix and transition zone stronger, thus the compressive strength of the concrete is dependent on the coarse aggregate quality. In medium strength concrete, Dolerite aggregate concrete exhibited higher compressive strength of 60 MPa which is 10-20% higher than other aggregate concretes. This is because of its rough texture and high crushing strength of the aggregate. Also the angular shape of the aggregate and rough texture makes the mechanical interlocking better between the aggregate and cement mortar. There was no significant difference in the compressive strength of concrete other than Dolerite aggregate. The concrete of strength 70 MPa was achieved with the help of Silica Fume. The concrete made with igneous rock such as Dolerite and Granite has produced higher compressive strength of 75 and 74 MPa respectively. The rough surface texture enhances the mechanical bond between the cement matrix and aggregate. The mineralogical composition also has considerable influence on the strength of the concrete. The concrete with carbonate aggregate such as Limestone and Dolomitic Limestone produced the compressive strength of 70 MPa each. The concrete made with these two aggregate concrete produced compressive strength higher than Quartzite and River Gravel aggregate concrete. The strength development of these carbonate aggregate concrete is due to chemical bonding between the aggregate and cement matrix. In all concrete grades, the Limestone aggregates have produced higher compressive strength than Dolomitic limestone which may due to the higher chemical interaction between the Limestone aggregate and the cement matrix. The Quartzite and River Gravel aggregate concrete yielded lower compressive strength in all the concrete mixes. This is due to the smooth surface texture and rounded shape which makes the bond weaker between the cement mortar and aggregate.

4.4 FRACTURE PROPERTIES OF CONCRETE

a) Fracture Energy

The prismatic specimens of size 500x100x100 mm were cast in steel molds and a notch of depth 40 mm was cut at the mid span of the specimen 24 hours before testing using a saw with a diamond blade. A 100t servo controlled Universal Testing Machine is used to test the specimens. A LABVIEW program was developed to remotely control the testing of the concrete specimen through the cross head travel readings. During testing a seating load of 0.05 kN was placed on each specimen followed by a constant opening displacement rate of 0.4-0.65 mm/Sec. Tests lasted between 8-12 minutes, depending upon the specimen compressive strength and aggregate type. However, all specimens were loaded to reach the maximum load approximately 60 seconds after the start of the test, as recommended by RILEM (1985). Fracture energy is the energy dissipated per unit area during the formation of a crack. The energy is dissipated within the fracture process zone; the region in front of a crack tip where the stress decreases as the crack opens. The area of fracture is the projected area on a plane perpendicular to the direction of stress. The full testing setup is presented in Fig 3.

As discussed above, fracture energy is determined using a notched beam in three-point bending. The average deflection is measured at the centerline of the beam. Load-deflection curves are plotted, with the energy, W0, representing the area under the curve. RILEM (1985) and Hillerborg (1985) suggest that fracture energy be calculated using the following expression:

$$G_F = \frac{W_o + mg\delta_o}{A}$$

Where,

Gf = fracture energy (N-m);

W0=area under the load-deflection curve (N-m);

M=weight of the beam between the supports and the loading frame (knee);

G=acceleration due to gravity;

δ0=final deflection of the beam (m);

A=cross-sectional area of the beam above the notch (m2).

Fig 3: Servo Controlled UTM for Fracture Test

The need for the term 'mg', results from the fact that the imposed load from the machine is not the only load acting on the specimen during the test; the weight of the specimen between the supports and the weight of the testing equipment supported by the specimen also play a role. Therefore, the measured load-deflection curve does not account for the full load on the beam and, thus, does not reflect the total energy necessary to cause fracture. The fracture energy for different aggregate concretes was discussed in Table 7.

Table 7: Fracture Energy of Concrete with Different types of Coarse Aggregate

Mix Code	Mean Area under the curve (W0) (Nm)	Peak Load (kN)	Max. Deflection (ä0) (mm)	Weight of the specimen (m) (kg)	Fracture Energy (Gf) (Nm/m2)	Characteristic length (lch) (m)
D 30	1.86	4.67	1.47	13.386	310.78	0.103
DL 30	1.65	4.90	1.35	13.280	275.94	0.076
G 30	2.12	3.58	2.36	14.578	352.38	0.119
L 30	2.15	3.48	2.11	12.454	353.38	0.110
Q 30	2.05	3.27	1.00	12.318	343.54	0.127
RG 30	1.52	3.22	1.41	12.550	250.87	0.086
D 50	2.11	5.55	1.5	12.930	353.61	0.118
DL 50	1.96	5.15	1.88	12.824	326.56	0.112
G 50		4.17		12.526		
L 50	2.37	4.42	2.00	12.495	395.4	0.087
Q 50	1.72	5.48	1.55	12.486	287.01	0.074
RG 50	1.52	4.34	2.37	12.330	254.37	0.067
D 70	1.57	5.24	1.39	12.704	262.51	0.052
DL 70	1.35	5.65	2.21	12.784	238.4	0.057
G 70	1.67	4.00	1.90	12.496	278.4	0.056
L 70	1.13	4.71	0.92	12.316	210.00	0.049
Q 70	1.58	4.56	2.07	12.238	265.12	0.069
RG 70	1.14	3.92	1.54	12.338	188.72	0.047

For all grades of concrete, the concrete containing granite aggregate yields a significantly higher fracture energy than concrete with other aggregate. In NSC, except Dolomitic limestone and River gravel, other aggregate concrete produced similar fracture energy results (Fig 4 (a) & (b)). This is because of the weaker cement mortar matrix and interfacial zone. When loaded, the cracks travelled around the aggregate and left the coarse aggregate undamaged. Also the Granite aggregate concrete has the maximum deflection of 2.36 mm followed by limestone and Dolerite with a deflection of 2.11 and 1.47 mm respectively

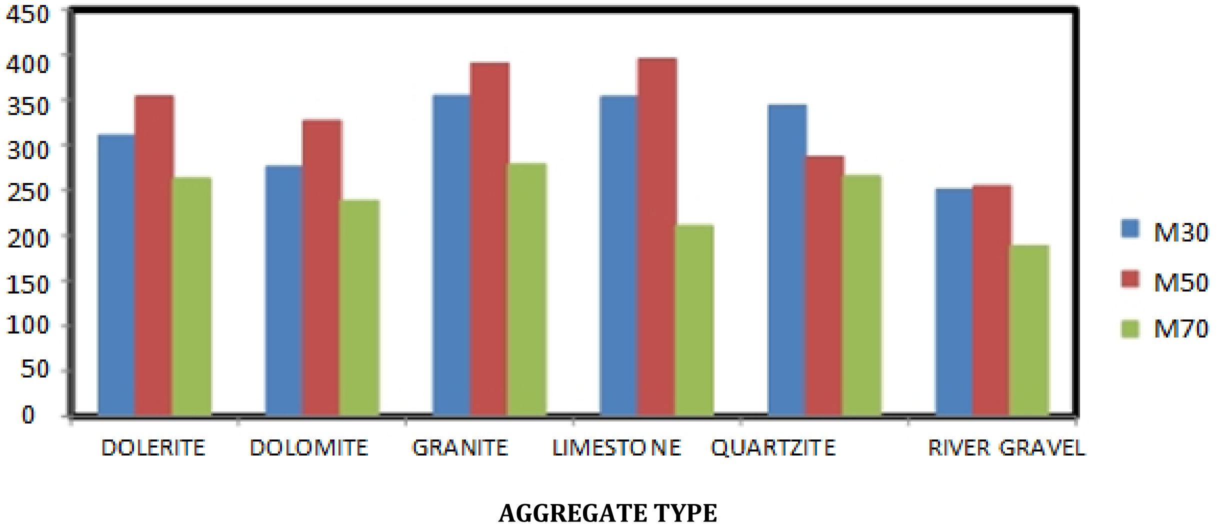

Fig 4 (a): Effect of Coarse aggregate type on Fracture Energy of various grades of concrete

In case of medium strength concrete, Limestone aggregate concrete yielded higher fracture energy of 395 Nm/m2 as a result of good chemical interaction between the aggregate and cement paste which makes the interfacial zone stronger. This strong interfacial zone absorbs more energy before the concrete specimen fails which resulted in higher fracture energy followed by concrete with Dolerite aggregate with fracture energy of 353 Nm/m2. Concrete with Quartzite and River Gravel aggregate yielded poor results of 287 and 254 Nm/m2 respectively, due to its shape and texture.

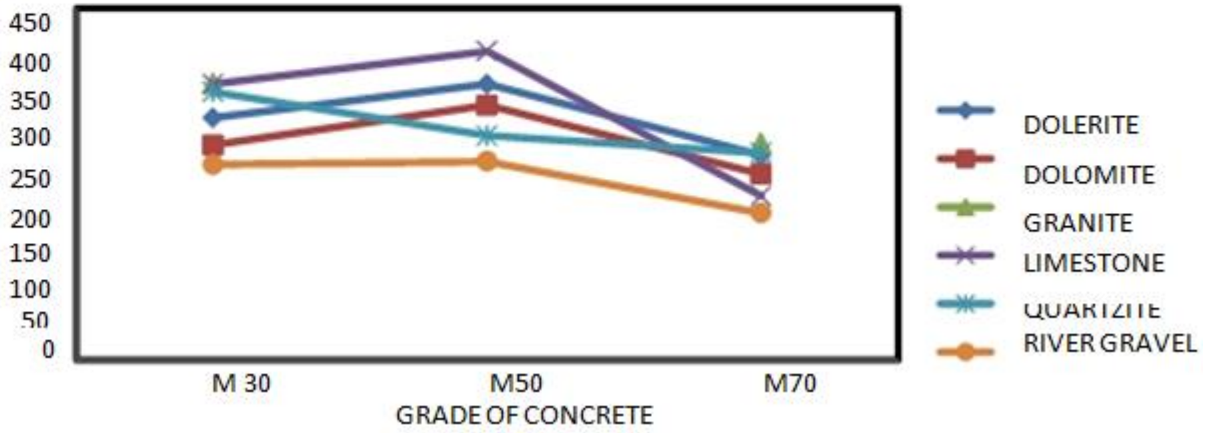

Fig 4 (b): Effect of Coarse aggregate types on Fracture Energy on various grades of concrete

For high strength concrete, fracture energy for all aggregate concrete reduced by 25-47% when compared with medium concrete, even though the compressive strengths were higher by 25%. This is might be because of the addition of silica fume which has a negative effect on fracture energy for a given type of concrete class (Tasdemir et al,1999). Silica fume reacts with calcium hydroxide forming the interface zone and cement matrix much stronger than then aggregate. Thus, when the load is applied, the cracks traversed through the aggregate and reduces the fracture energy as well the characteristic length. In this case, concrete with Granite, Quartzite and Dolerite aggregate yielded good results when compared to other aggregate concrete. In all the concrete mixes, River Gravel produced lower fracture energy and compressive strength. In all the cases, the specimen failed by debonding of the cement matrix which is because of the round shape and smooth texture of the aggregate. The Load-Deflection curves for various grades of concrete are presented in Fig 5 to Fig 7.

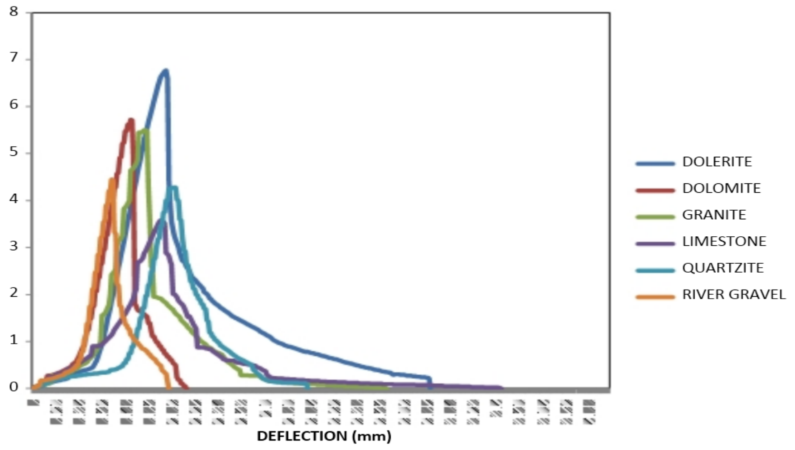

Fig 5: Load-Deflection curves for Normal Strength Concretes

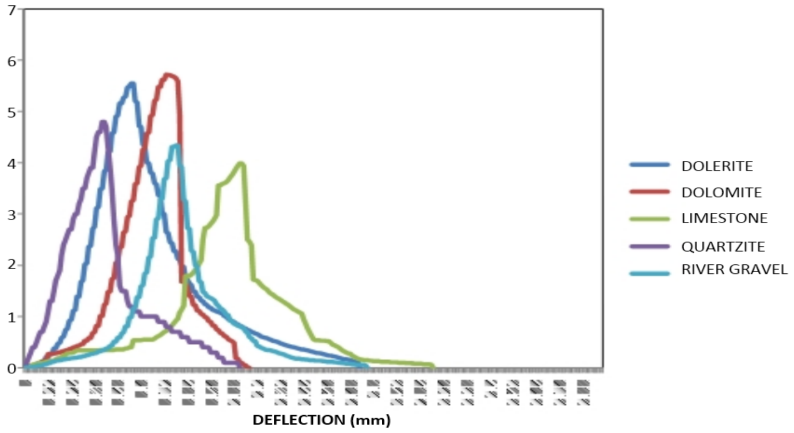

Fig 6: Load-Deflection curves for Medium Strength Concretes

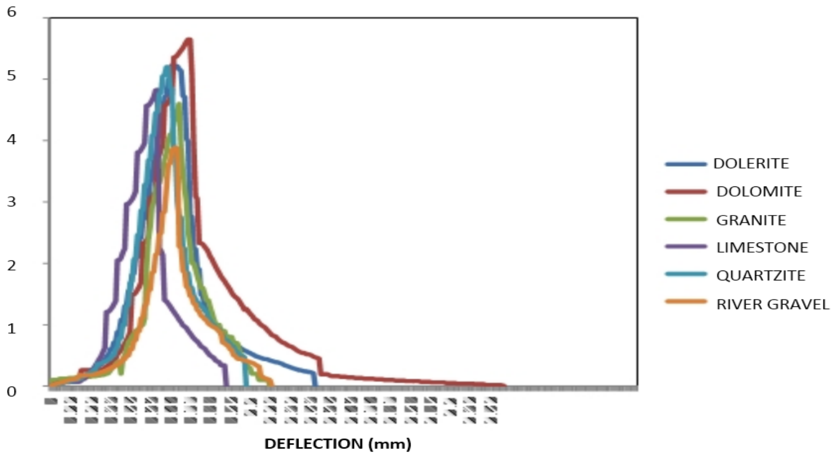

Fig 7: Load-Deflection curves for High Strength Concretes

The brittleness of concrete can be expressed by its characteristic length (l_{ch}). The characteristic length of the concrete depends on the compressive strength and fracture energy of the concrete. The results show that the increase in the compressive strength and the fracture energy decreases the characteristic length of the concrete, which indicates the concrete behaves more like a brittle material in HSC.

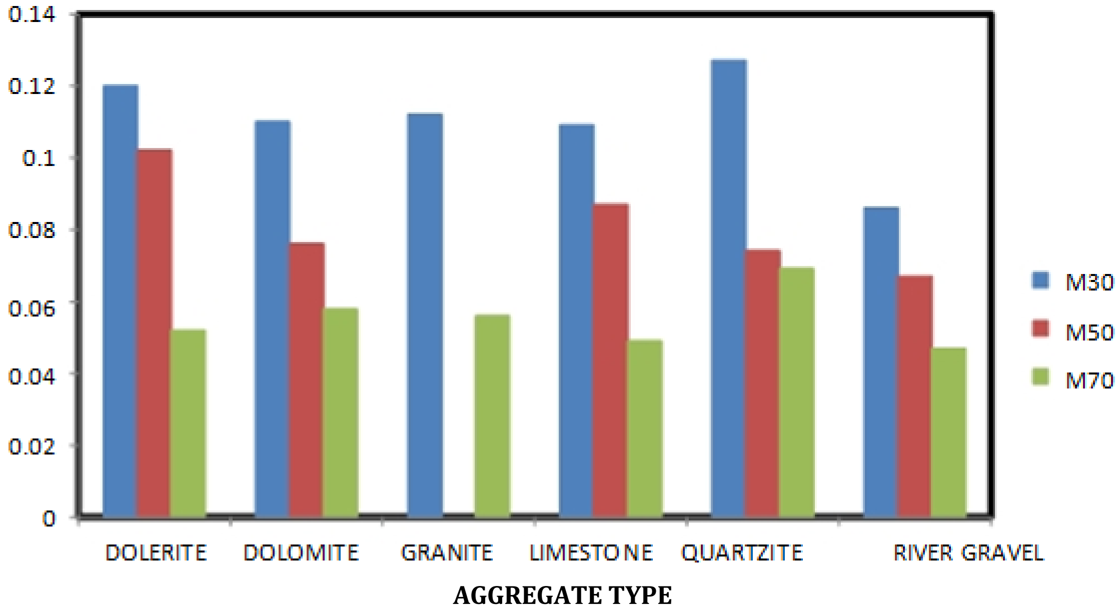

Fig 8: Effect of Coarse aggregate type on Characteristic length of different concrete grades

b) Fracture Surfaces of Concrete

The fractured surfaces of all the concrete mixes with different coarse aggregate type are presented in Fig 9 to 14.

(a) (b) (c)

Fig 9: Fractured surfaces of Dolerite Concrete for: (a) M 30; (b) M 50; and (c) M 70

a) (b) (c)

Fig 10: Fractured surfaces of Dolomitic Limestone Concrete for: (a) M 30; (b) M 50; and (c) M 70

(a) (b) (c)

Fig 11: Fractured surfaces of Granite Concrete for: (a) M 30; (b) M 50; and (c) M 70

(a) (b) (c)

Fig 12: Fractured surfaces of Limestone Concrete for: (a) M 30; (b) M 50; and (c) M 70

(a) (b) (c)

Fig 13: Fractured surfaces of Quartzite Concrete for: (a) M 30; (b) M 50; and (c) M 70

a) (b) (c)

Fig 14: Fractured surfaces of River Gravel Concrete for: (a) M 30; (b) M 50; and(c) M 70

The study on the fracture surfaces shows that in normal strength concrete, the failure always happens in the cement matrix and/or interfacial zone which results in de-bonding of aggregate from the mortar. Where as in medium strength concrete, the crack travelled through both the aggregate and cement matrix. This is because of the lower water cement ratio, which densifices the cement phase and almost equal to the strength of aggregate.

High strength concrete, the addition of silica fume made the interface zone and cement matrix much stronger than aggregate phase resulted in the shearing of aggregate while loading. In all the cases, the failure of concrete with River gravel is by de-bonding of aggregate from the cement matrix. The reason is because of the aggregates smooth surface texture and round shape which results in poor interlocking between the aggregate and cement matrix.

5. CONCLUSIONS

5.1 SUMMARY

This report is aimed to provide a better understanding of the effects of aggregate type on the strength and fracture characteristics of normal and high strength concretes. Special consideration has been given to fracture energy and characteristic length of concrete.

The concrete in this study incorporates six different types of coarse aggregates such as Dolerite, Dolomitic limestone, Granite, Limestone, Quartzite and River Gravel with sizes of 29 mm. Water-to cementitious materials ratios range from 0.3 to 0.50. Compressive strengths range from 30 MPa to 70 MPa. Eighteen batches (6 normal-strength concrete and 12 high-strength concrete) of 3 cubes and prismatic specimens each were cast and tested. The results of 54 compression and 54 fracture energy tests are reported. Concretes were tested at an age of 28 days. Fracture energy tests were performed using a servo controlled Universal Testing Machine of capacity 100t.

5.2 CONCLUSIONS

The following conclusions are based on the findings for the materials used and tests performed in this study:

1. In normal strength concrete, the compressive strength produced by all types of aggregates is almost comparable, though there is a significant variation in the mechanical properties of the coarse aggregates. This result indicates that the aggregate type has no impact as the interfacial zone is regarded as the weakest link in the normal strength concrete.

2. In case of medium strength concrete, Dolerite aggregate concrete has the highest compressive strength of 60 MPa where as the other aggregate concrete has no significant difference in the compressive strength and the strength ranges from 51-55 MPa.

3. For high strength concrete, Dolerite and Granite aggregate concrete exhibits higher compressive strength of 75 MPa, the carbonate aggregate produces strength of 70 MPa, Quartzite and River Gravel aggregate concrete produced strength of 66 and 63 MPa respectively.

4. In normal and high strength concretes, concrete containing Granite aggregates yielded higher fracture energies ranging from 278-354 Nm/mm2 than concrete containing other coarse aggregates. This is because of the mechanical and physical characteristics of coarse aggregate.

5. In normal strength concrete, there is no significant variation in the fracture energies of concrete except River gravel which yielded a lower value of 254 Nm/m2.

6. In medium strength concrete, Limestone concrete absorbs more energy before when compared to other aggregate.

7. In case of high strength concrete, the addition of silica fume has a negative effect on the fracture energy of concrete for all aggregate types, even though the effect on compressive strength of concretes is positive

8. In all the concrete grades, concrete with River gravel aggregate, produces lower fracture energy because of the poor bonding between the aggregate and cement phase.

5.3 FUTURE WORK

Although this study provides insight into the effects of aggregate type on normal and high-strength concrete, a number of important questions cannot be answered with the available data. Of particular interest are the effects of aggregate size, volume on the compressive strength and fracture energy of concrete containing different types of coarse aggregates. The test results analyzed in this study are for concrete compressive strengths ranging from 30, 50 and 70 MPa. To obtain a complete understanding of the effects of aggregate type, tests are required for compressive strengths spanning between the various strength ranges, and also at later test ages for normal-strength concretes and earlier test ages for high-strength concretes. Another aspect of the current study that needs further examination is the relative influence of larger maximum aggregate size and a coarse aggregate content for both normal and high-strength concretes. In the present study the notch depth and size of the specimen was kept constant. Fracture test on concrete can be extended by varying the notch depth of the specimen, loading rate and size of the specimen. Finally, a microscopic analysis of the concrete matrix and interfacial transition zone is needed to develop a complete understanding of the effects of aggregate on concrete. Only through a full understanding of the response of concrete under general loading, the behavior of the material can be understood.

REFERENCES

1. Abdullahi M. Effect of aggregate type on compressive strength of concrete. International Journal of Civil and Structural Engineering. 2012; 2(3):791-780.

2. Aitcin PC, Mehta PK. Effect of coarse-aggregate characteristics on mechanical properties of high-strength concrete. ACI Materials Journal. 1990; 87(2):103-107.

3. Alexander MG, Milne TI. Influence of cement blend and aggregate type on stress-strain behavior and elastic modulus of concrete. ACI Materials Journal. 1995; 92(3):227-235.

4. Almusallam AA, Beshr H, Maslehuddin M, Amoudi O. Effect of silica fume on the mechanical properties of low quality coarse aggregate concrete. Cement and Concrete Composites. 2004 ; 26:891-900.

5. Aydin S, Yazici H, Yardimci MY, Yiğiter H. Effect of aggregate type on reactive powder concrete. ACI Materials Journal. 2010; 107(5):441-449.

6. Baalbaki W, Benmokrane B, Chaallal O, Aitcin PC. Influence of coarse aggregate on elastic properties of high performance concrete. ACI Materials Journal. 1991; 88(5):499-503.

7. Chen B, Liu J. Effect of aggregate on the fracture behavior of high strength concrete. Construction and Building Materials. 2004; 18:585-590.

8. Cetin A, Carrasquillo RL. High-Performance Concrete: Influence of Coarse Aggregates on Mechanical Properties. ACI Materials Journal. 1998; 95(3):252-259.

9. Darwin D, Barham S, Kozul R, Luan S. Fracture energy of high-strength concrete. ACI Materials Journal. 2001; 98(5):410-417.

10. Gettu R, Bazant ZP, Karr E. Fracture properties and brittleness of high strength concrete. ACI Materials Journal. 1990; 87(6):608-618.

11. Hassanzadeh M. The influence of the type of coarse aggregates on the fracture mechanical properties of high strength concrete. FRAMCOS. 1998; 3:161-169.

12. Kaplan MF. Flexural and compressive strength of concrete as affected by the properties of coarse aggregates. Journal of the American Concrete Institute. 1959; 30(11):1193-1208.

13. Larrard F, Belloc A. The influence of aggregate on the compressive strength of normal and high strength concrete. ACI Materials Journal. 1997; 94(5):417-425.

14. Petersson PE. Fracture energy of concrete: practical performance and experimental results. Cement and Concrete Research. 1980; I0:91-101.

15. Sengul O, Tasdemir C, Tasdemir MA. Influence of aggregate type on mechanical behavior of normal- and high-strength concretes. ACI Materials Journal. 2002; 99(6):528-533.

16. Tasdemir C, Tasdemir AM, Mills N, Barr IG, Lydon LD. Combined effects of silica fume, aggregate type, and size on post peak response of concrete in bending. ACI Materials Journal. 1999; 96(1):74-82.

17. Tarun Ozturan, Cengizhan Cecen. Effect of coarse aggregate type on mechanical properties of concrete with different strength. Cement and Concrete Research. 1997; 27(2):65-170.

18. Wu K, Chen B, Yao W, Zhang D. Effect of coarse aggregate type on mechanical properties of high performance concrete. Cement and Concrete Research. 2001; 3:1421-1425.

19. Yan YC. The effects of mix variables on concrete fracture mechanics parameters. FRAMCOS. 1995; 2:111-118.