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Effect of sand-to-aggregate volume ratio on mechanical properties of concrete

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ABSTRACT: The major portion of the volume of concrete is occupied by the fine and coarse aggregates. Therefore, an extensive experimental investigation was carried out to evaluate the effect of different sand to aggregate volume ratio (*s/a*) on the mechanical properties of concrete. For investigation, cylindrical concrete specimens (100 mm diameter and 200 mm height) were made with different *s/a* ratio (0.36, 0.40, 0.44, 0.48, 0.52 and 0.56), cement content (340 kg/m^3 and 450 kg/m^3), W/C (0.45 and 0.50) and maximum aggregate size (MAS) (12 mm and 19 mm). The concrete samples were tested for compressive strength, tensile strength and Young's modules at the ages of 7 days, 14 days and 28 days. It was found that irrespective of the cement content and W/C, the optimum *s/a* ratio was found to be 0.40 and 0.44 for maximum aggregate size 12 mm and 19 mm respectively.

1 INTRODUCTION

Mechanical properties of concrete, such as compressive strength, tensile strength, flexural strength and modulus of elasticity, etc. are necessary during design of a reinforced concrete structure. Flexural strength, elastic modulus, splitting tensile strength, etc. are generally correlated with compressive strength of concrete in design codes (Nagwani & Deo 2014). These mechanical properties of concrete are highly influenced by the constituent materials of concrete. The ingredients of concrete such as cement, water, coarse aggregate, fine aggregate, mineral and chemical admixtures are proportioned based on the requirement of strength and workability (Deep et al. 2010). As the major portion of concrete is occupied by aggregates (60% ~ 80%), therefore strength of concrete, workability, and other properties as well as cost per unit volume of concrete are greatly affected by the aggregate volume of concrete (Sagoe-Crentsil et al. 2001).

Several studies have been conducted considering maximum aggregate size, strength of aggregate, texture, W/C, and cement type (Bloem & Gaynor 1963, Mir et al. 2017, Mohammed et al. 2017). However, a few studies focused on the relative volume proportion of sand and aggregate. A research was conducted to investigate the effect on compressive strength for sand-to-aggregate (fine aggregate plus coarse aggregate) volume ratio (*s/a*) of 0.40 and 0.45 and concluded that the compressive strength increases with the increase of the volume of sand (Mohammed et al. 2017). Excess proportion of sand volume may reduce workability as well as strength of concrete. Bashandy & Soliman (2013) conducted a study considering fine aggregate to coarse aggregate volume ratio as 0.0, 0.5, 1.0, 2.0 and 3.0. They found the optimum ratio of fine aggregate to coarse aggregate as 0.5. In another study, it was concluded that the flexural strength of concrete is dependent upon the coarse aggregate content in the mixture proportion and increases with the increase of coarse aggregate content (Moavenzadeh & Kuguel 1969). Other researchers also concluded that the compressive strength of concrete increases with the increase of coarse aggregate content until it reaches a critical volume (Ruiz 1966).These results indicate that there may have an optimum *s/a* to get the maximum compressive strength of concrete. It is also expected that this ratio will also govern the durability properties, such as carbonation and chloride ingress of concrete.

With the above-mentioned background, an extensive experimental investigation was carried out by varying the sand to aggregate volume ratio (*s/a*), water to cement (W/C) ratio, cement content and maximum aggregate size (MAS). Compressive strength, tensile strength and elastic modulus of concrete were compared for different *s/a* and several relationships between compressive strength and elastic modulus; tensile strength and compressive strength are proposed to evaluate the effect of *s/a* on the mechanical properties of concrete.

Table 1. Material properties.

Type of Aggregate	Coarse Aggregate	Fine Aggregate	Test Method
Bulk SSD specific gravity	2.83	2.48	ASTM C127-15
Absorption	1.49%	3.18%	ASTM C127-15
Unit weight (oven dry), kg/m^3	1528	1527	ASTM C29
Unit weight (SSD), kg/m^3	1551	1576	ASTM C29
Abrasion	14%	-	ASTM C131
FM	6.45 (MAS–12 mm) 6.67 (MAS–19 mm)	2.46	ASTM C136

Table 2. Mixture proportions of concrete.

MAS (mm)	W/C	s/a	Unit contents (kg/m^3)			
			Cement	Water	Fine aggregate	Coarse aggregate
12	0.45	0.36	340	153	640	1300
		0.40			712	1219
		0.44			783	1138
		0.48			854	1056
		0.52			925	975
		0.56			996	894
	0.50	0.36		170	625	1269
		0.40			695	1190
		0.44			764	1111
		0.48			834	1031
		0.52			903	952
		0.56			973	873
	0.45	0.36	450	202.5	565	1146
		0.40			627	1075
		0.44			690	1003
		0.48			753	931
		0.52			815	860
		0.56			878	788
	0.50	0.36		225	545	1105
		0.40			605	1036
		0.44			666	967
		0.48			726	898
		0.52			786	829
		0.56			847	760
19	0.45	0.36	340	153	640	1300
		0.40			712	1219
		0.44			783	1138
		0.48			854	1056
		0.52			925	975
		0.56			996	893
	0.50	0.36		170	625	1269
		0.40			695	1190
		0.44			764	1110
		0.48			834	1031
		0.52			903	952
		0.56			973	873
	0.45	0.36	450	202.5	565	1146
		0.40			627	1075
		0.44			690	1003
		0.48			753	931
		0.52			815	860
		0.56			878	788
	0.50	0.36		225	545	1105
		0.40			605	1036
		0.44			665	967
		0.48			726	898
		0.52			786	829
		0.56			847	760

2 EXPERIMENTAL METHOD

2.1 *Materials*

Crushed granite stone and river sand as shown in Figure 1 were used as coarse and fine aggregates respectively. Two different maximum aggregate size (MAS), such as 12 mm and 19 mm were used. Gradation curves of the aggregates are shown in Figure 2. The gradations of both fine and coarse aggregates were controlled as per the requirements of ASTM C33. Both course and fine aggregates were tested for specific gravity, absorption capacity, unit weight, and fineness modulus as per ASTM standards. Coarse aggregate samples were also tested for abrasion resistance. The results are summarized in Table 1. Blended cement, CEM Type II A-M (as per BDS EN 197–1:2000) was used as a binder material. It consists of 80–94% clinker and the rest 6–20% as mineral admixtures including gypsum. Potable tap water was used as mixing water.

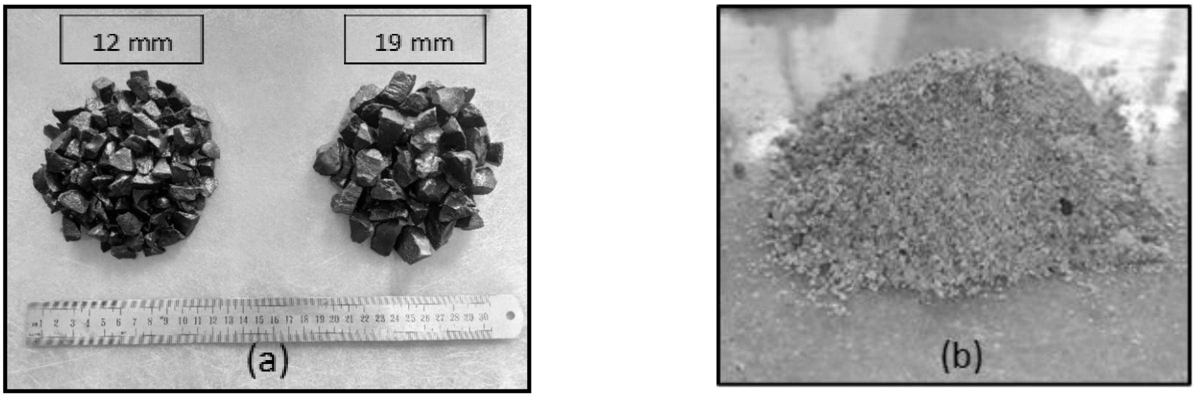

Figure 1. (a) Coarse aggregate (MAS – 12 mm and 19 mm). (b) River sand.

2.2 *Mixture Proportions, Specimen Preparation and Testing*

Table 2 summarizes the mixing proportions of concrete investigated in this study. Mixture proportions were prepared by varying *s/a* (0.36, 0.40, 0.44, 0.48, 0.52 and 0.56), cement content (340 kg/m^3 and 450 kg/m^3), W/C (0.45 and 0.50) and maximum aggregate size(MAS) (12 mm and 19 mm). Using these mixture proportions, 576 cylindrical concrete samples (height of 200 mm and diameter of 100 mm) were made for 48 different cases as per ASTM C192. After pouring concrete in the cylindrical steel molds, the specimens were covered with a plastic sheet to avoid evaporation of water from concrete. After 24 hours from pouring of concrete, the specimens were de-molded and cured under water as per ASTM C192 till the age of testing.

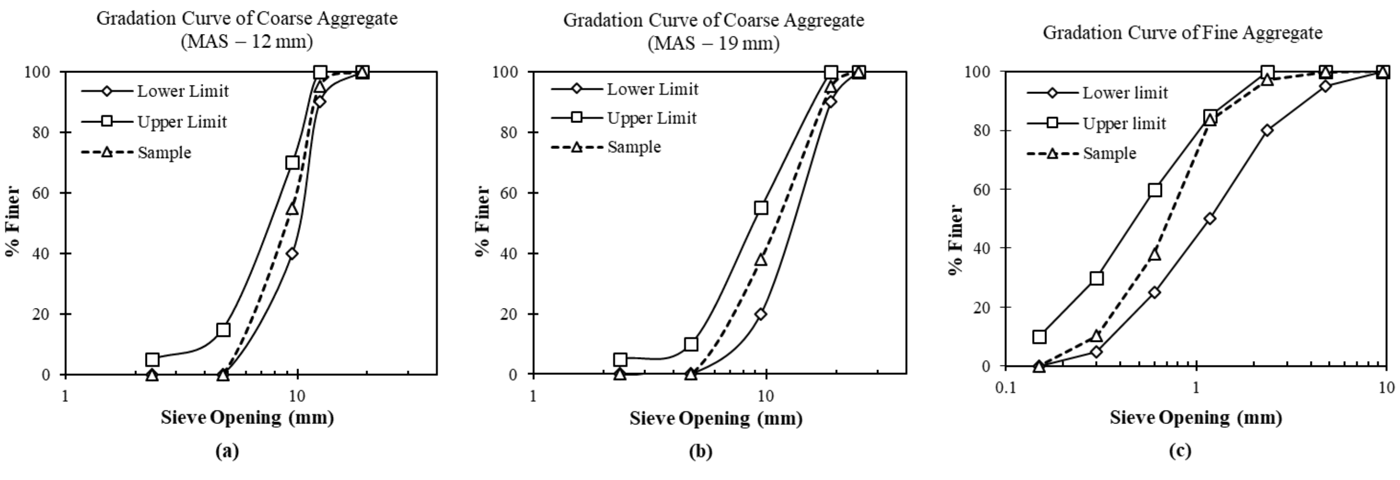

Figure 2. Gradation curves - (a) MAS – 12 mm coarse aggregate (b) MAS – 19 mm coarse aggregate (c) fine aggregate.

At the age of 7, 14, and 28 days, concrete specimens were tested using a 2000 KN compression machine as per ASTM C39. A compressometer (mounted with two dial gauges) was fastened over the specimen. The gauge length was 100 mm. During loading, deformations were recorded. The stress of concrete at the strain level of 0.0005 was determined from the stress-strain curve and then Young’s modulus of concrete was determined(Mohammed et al. 2017). Splitting tensile strength of concrete samples was determined at the age of 28 days as per ASTM C496.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 *Effect of Sand to Aggregate Volume Ratio (S/A) on Compressive Strength*

The variation of compressive strength of concrete with respect to *s/a* ratio (0.36, 0.40, 0.44, 0.48, 0.52 and 0.56) is shown in Figure 3. From Figure 3, it can be summarized that irrespective of variation of cement content and W/C for concrete made with MAS of 12 mm, compressive strength increases with the increase of *s/a* from 0.36 to 0.40 and beyond that it decreases with the increase of *s/a* till 0.56. Similarly, for concrete made with MAS of 19 mm, with the increase of *s/a* from 0.36 to 0.44, the compressive strength increases and decreases again with the increase of *s/a* to 0.56. These observations are found irrespective of the variation of cement content and W/C investigated in this study.

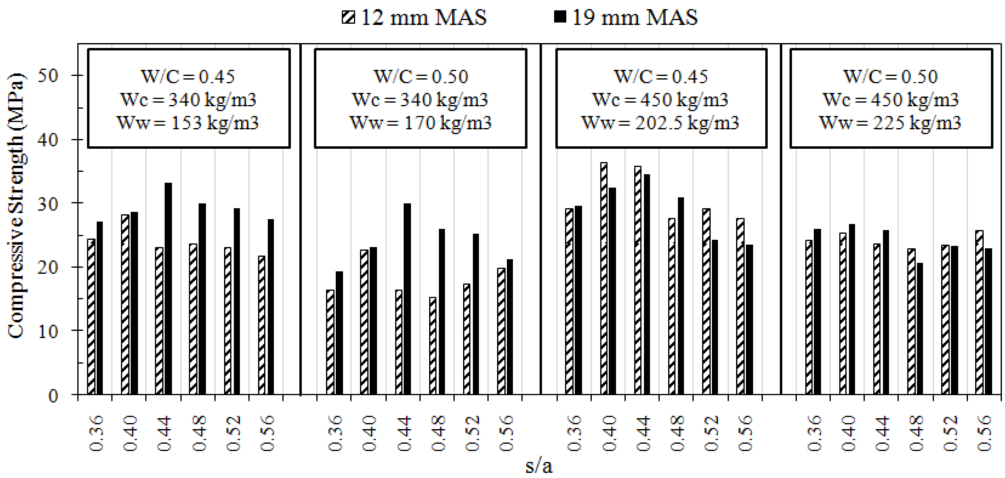

Figure 3. Effect of sand to aggregate volume ratio on compressive strength.

Mohammed & Rahman (2016) also drew the similar conclusion that the compressive strength increases with the increase of *s/a* from 0.36 to 0.44 for a maximum aggregate size of 19.0 mm. For 19 mm of MAS, it is expected that a compact aggregate mix is produced when fine and total aggregate ratio (*s/a*) is 0.44. The ratio becomes 0.40 for 12.0 mm of MAS. It is also understood that the optimum value of *s/a* ratio will depend on MAS. The optimum *s/a* ratio is reduced for a lower value of MAS. It is also expected that the durability parameters such as chloride ingress and carbonation of concrete will be varied with the variation of *s/a* ratio. Investigations on these parameters are still continuing and will be reported later.

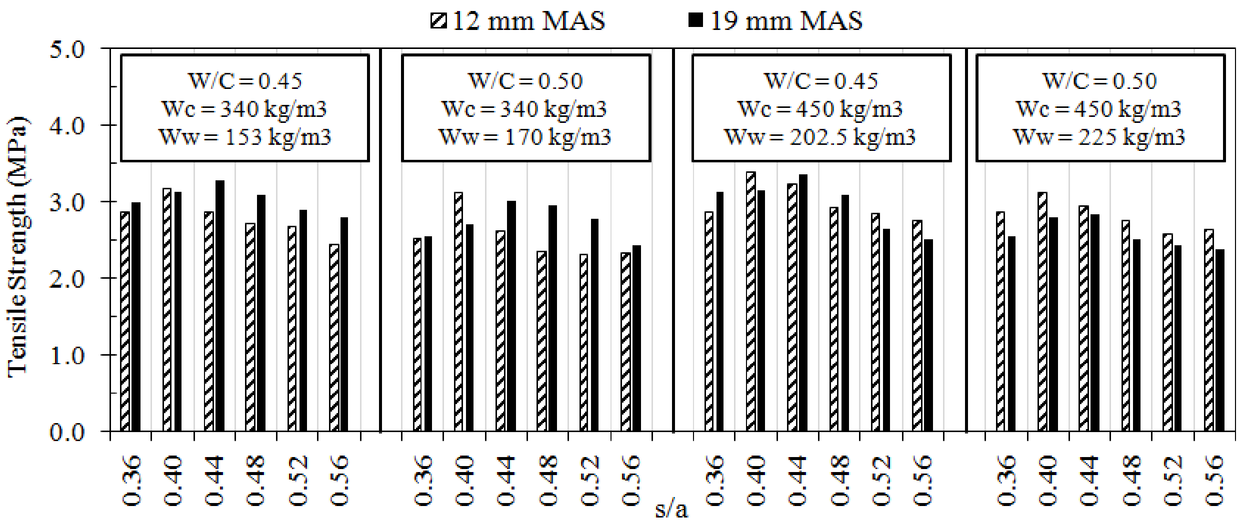

Figure 4. Effect of sand to aggregate volume ratio on tensile strength.

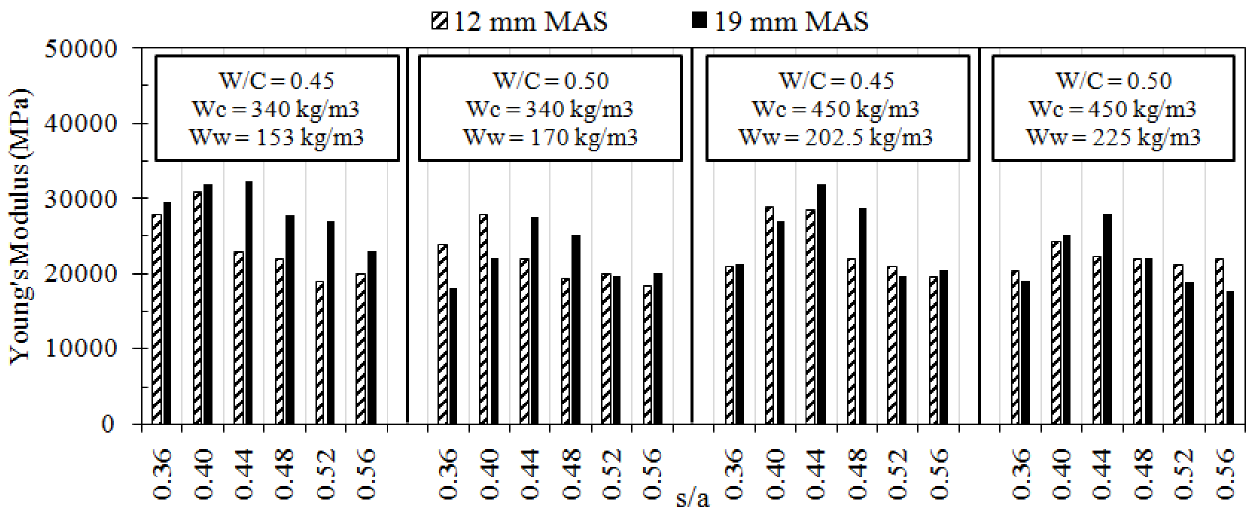

Figure 5. Effect of sand to aggregate volume ratio on Young's modulus.

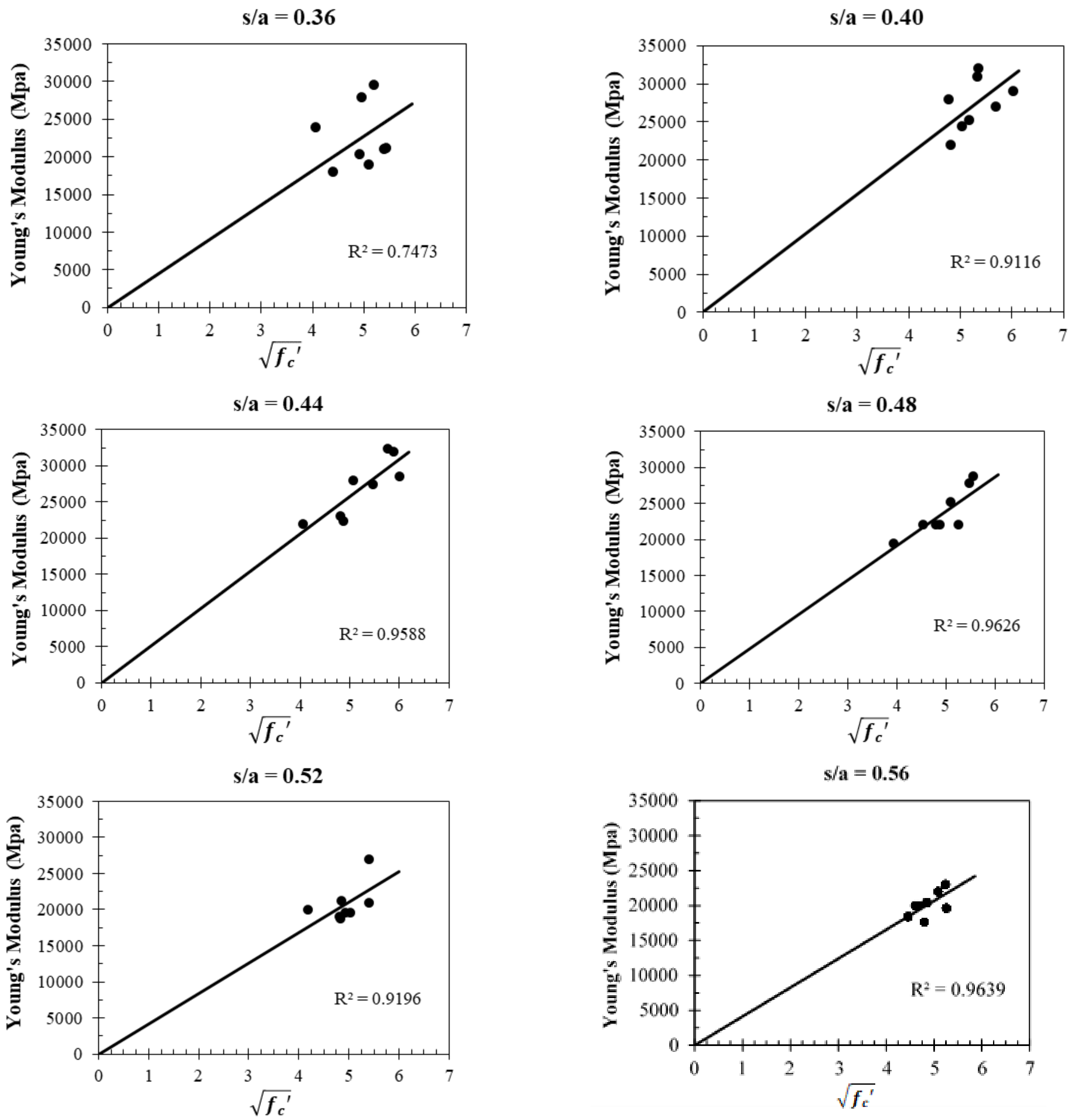

Figure 6. Relationship between Young's modulus and compressive strength.

3.2 *Effect of Sand to Aggregate Volume Ratio (S/A) on Tensile Strength*

The effect of *s/a* ratio on the splitting tensile strength of concrete is shown in Figure 4. From this figure, it is also found that the optimum tensile strength of concrete is observed at *s/a* ratio of 0.40 and 0.44 for MAS of 12.0 mm and 19.0 mm respectively. From this observation, it is realized that compressive strength of concrete needs to be correlated with tensile strength of concrete considering the effect of *s/a* ratio that does not reflect in the design guidelines, such as ACI 318-14.

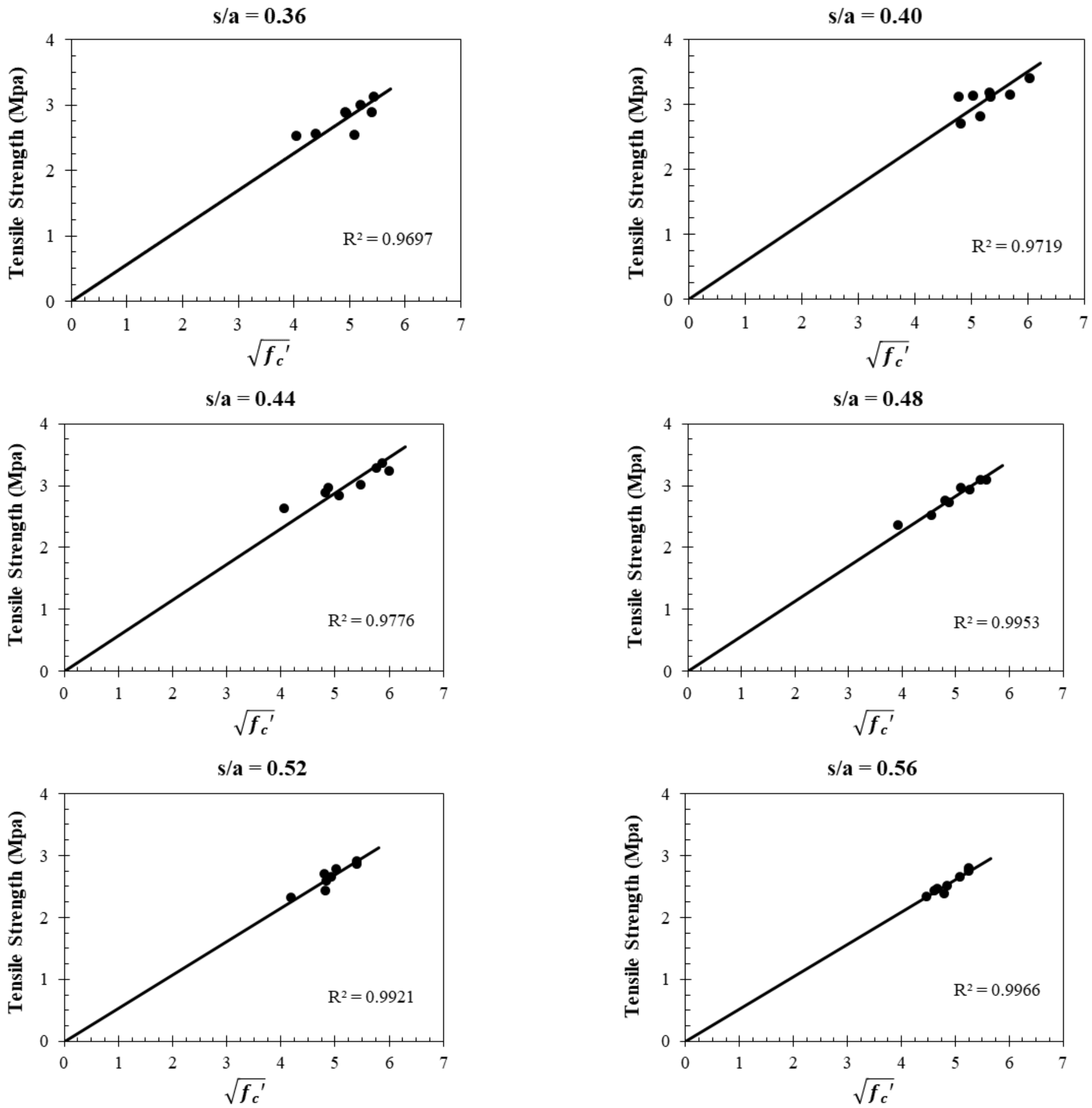

Figure 7. Relationship between compressive strength and tensile strength.

3.3 *Effect of Sand to Aggregate Volume Ratio (S/A) on Young's Modulus*

Figure 5 illustrates the effect of *s/a* ratio on Young's modulus of concrete. It can be observed from Figure 5 that Young's modulus of concrete also followed the similar trends of results as observed for compressive as well as tensile strength of concrete. From this observation, it is also understood that compressive strength of concrete needs to be correlated with Young's modulus of concrete considering the effect of *s/a* ratio that does not reflect in the design guidelines, such as ACI 318-14.

3.4 *Relationship between Young's Modulus and Compressive Strength*

Figure 6 shows the relationships between Young's modulus and the compressive strength of concrete for different s/a ratio. As the Young's modulus of concrete is varied with s/a ratio, therefore an attempt has been made to correlate Young's modulus of concrete with compressive strength by introducing a factor related to s/a ratio. Based on Figure 6, the relationship between Young's modulus and compressive strength of concrete is proposed as follows (ACI 318-14):

$$E_c = 4732\,\phi\,\sqrt{f_c{}'} \qquad (1)$$

where E_c denotes Young's modulus in MPa and $f_c{}'$denotes the compressive strength of concrete in MPa. The values of ϕ are 0.96, 1.1, 1.08, 1.01, 0.89 and 0.87 for *s/a* of 0.36, 0.40, 0.44, 0.48, 0.52 and 0.56, respectively. According to ACI 318-14, the value of ϕ is 1.0 without considering the effect of *s/a*. Other researchers also proposed the relationships without considering the effect of *s/a* (Kesegić et al. 2008).

3.5 *Relationship between Compressive Strength and Tensile Strength*

The variations of splitting tensile strength of concrete with compressive strength for different *s/a*are shown in Figure 7. Based on the experimental data of Figure 7, the tensile strength of concrete can be correlated with compressive strength by the following equation (ACI 318-14):

$$f_t = 0.56\,\psi\,\sqrt{f_c{}'} \qquad (2)$$

Where f_t denotes the splitting tensile strength in MPa and $f_c{}'$ denotes the compressive strength in MPa. The values of ψ are 1.01, 1.04, 1.02, 1.01, 0.96 and 0.93 respectively for *s/a* of 0.36, 0.40, 0.44, 0.48, 0.52 and 0.56.

4 CONCLUSIONS

Based on the experimental results of this study, the following conclusions are drawn:

- Irrespective of the W/C and cement content, the optimum *s/a* is found at 0.40 and 0.44 with respect to the mechanical properties of concrete investigated in this study for 12.0 mm and 19.0 mm of MAS respectively.
- The effect of *s/a* is necessary to be considered during formulations of empirical relationships between compressive and tensile strength, and compressive strength and Young's modulus of concrete.
- Relationships between Young's modulus and compressive strength; and splitting tensile strength and compressive strength of concrete are proposed considering the effect of *s/a*.

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