Jordan Journal of Civil Engineering, Volume **8**, No. **2**, **2014**

Assessment of the Strength of Remixed Concrete Structures

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ABSTRACT

This work presents an experimental investigation to study the effect of remixing on the strength of concrete. The compressive strength, the splitting tensile strength, the shear strength as well as the flexural strength for 6 different concrete mixes have been measured. The results of investigation showed that the strength of concrete may be improved by remixing, provided that the time between remixing and casting does not exceed 0.7 the initial setting time of cement. Further improvement is achieved when remixing is associated with adding fresh concrete. The results showed that the improvement in strength can be as high as 20%. The improvement in strength was found to be affected by the blend ratio.

KEYWORDS: Remixing, Compressive strength, Flexural strength, Splitting strength, Shear strength.

INTRODUCTION

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. It starts gaining strength from the instant of time since water is added to the dry mass of the ingredients (t = 0). Concrete thus prepared at t = 0, but placed into the mould at a time lag t, is bound to be adversely affected in strength (henceforth it is used to denote compressive strength, tensile strength, shear strength, flexural strength,… etc. and likewise) as well as other physical properties. Such t-hour concretes prepared at t = 0 and considered for moulding at a time lag t are known as the preset concretes which are prone to reduction in strength, primarily due to the onset of setting process within the mass (Neville and Brooks, 1987). As long as the time lag t remains limited between 0 and the initial setting time t_i, the preset concretes turn out to be the normal workable green concretes which can be easily cast into the moulds. But, when the time lag t exceeds t_i and is sufficiently beyond it, particularly towards the final setting time t_f, the hardship in moulding the partially set concretes is felt more and more (Mahboub and Cutshow, 2001).

The improvement in strength by revibration was noted to be more pronounced at earlier ages and is greatest in concretes liable to high bleeding, because the trapped water is expelled on revibration (Zaky, 1999). It is possible also that some of the improvement in strength is due to the relief of plastic shrinkage stresses around the aggregate particles. Despite these advantages, revibration is not widely used as it involves an additional step in the production of concrete, and hence increased cost. Also, if applied too late it may damage the concrete (Byfors, 1981).

The concept of strength variation of composite mixes has been studied by (Bairagi and Jhaveri, 1977).

Accepted for Publication on 20/2/2014.

Their studies revealed that strength with time lag variation of any mix is gradually decreasing in nature. The observations were made on evolving compressive strength, tensile strength and modulus of elasticity by considering two grades of cement to sand mortar ratios 1: 2 and 1: 3 each with water to cement ratios of 0.4 and 0.5 and cured for 28 days. Earlier studies on the strength aspect of preset mixes were carried out by (Bairagi and Kar, 1970) on the effect of presetting of cement on the mortar strength. Their studies revealed that the reduction in mortar strength occurs in case cement mortar is moulded after cement has undergone initial setting. They also reported that there is considerable improvement in strength if preset mortar is mixed with fresh one in suitable proportions. A large number of studies have been carried out by (Bairagi et al., 1989) on blending of two preset mixes covering the study of compressive strength, tensile strength and elastic modulus by using the concept of selfing; where selfing is a term attributed to the blending of the same mix type, but having different time lags. When the two delayed mixes are of different mix types, the process is called crossing (Bairagi, 2009).

Retampering of concrete by adding a controlled amount of water did not show any enhancement in its strength, but in some cases where the concrete was remixed after a time lag equal to about 90 minutes, the concrete achieved an enhancement in compressive strength.

Bairagi et al. (1989) concluded that self-mixing of concrete increases the compressive strength of concrete at a time lag equal to about half the initial setting time of cement by (10-20%) depending on the strength of concrete and the type of the used aggregates.

Accordingly, in this work, the effects of various factors on the strength of concrete blended with similar freshly mixed concrete are considered. These factors include:

1. The coarse aggregate type, where crushed basalt and rounded siliceous gravel were used. The two types of aggregate provide different shapes, surface textures, base materials as well as relative stiffness compared to the mortar.
2. The cement content, where two different cement contents were used for the crushed basalt.
3. The consistency of concrete, where concretes with normal and high slumps were considered for each type of aggregate.
4. The time lag between the mixing of the original concrete and adding the fresh concrete was considered.
5. The ratio between the original and fresh concretes used for remixing the concrete was taken into consideration.

OBJECTIVES OF RESEARCH

This work is undertaken in order to investigate the effect of the above given factors on the strength of concrete with the aim of investigating the effect of remixing on the concrete strength and the viability of salvaging partially preset concretes by blending with fresh concrete.

EXPERIMENTAL INVESTIGATION

The main parameters considered in this study are the type of coarse aggregate, the water to cement ratio, the blend ratio and the time lag. A total of six different concrete mixes were considered. Cylinder compressive strength, shear strength, splitting tensile strength and flexural strength were measured.

Properties of Constituent Materials

The concrete used in this investigation is a mixture of ordinary Portland cement (Type I Cement), basalt or siliceous coarse aggregate, siliceous fine aggregate (ASTM C33-01), and a commercially available super plasticizer complying with ASTM C 494 types A and F. The properties of the used Type I cement are given in Table 1.

Mixture Proportions

The mixes used in this study were designed along the guidelines of the standard (ACI 211.1-91, Reapproved 2009), (Kosmata et al., 2003). The composition of the different mixes is as given in Table 2.

Table 1. Properties of cement

Cement Type	Fineness (m^2/kg) ASTM C204-00	Initial Setting Time (min) ASTM C191-99	Final Setting Time (min) ASTM C191-99	Cube Strength (3 Days) MPa ASTM C109-99	Cube Strength (7 Days) MPa ASTM C109-99
Type I	346	86	312	28.6	36.4

Table 2. Concrete mixes proportions (for a cubic meter of concrete)

Mix Designation		Cement Type	Cement Content (kg/m^3)	Coarse Aggregate Type	Coarse Aggregate Content (kg/m^3)	Fine Aggregate Content (kg/m^3)	w/c ratio
1	Basalt-HL	Type I	450	Basalt	1200	750	0.25
2	Basalt-HH	Type I	450	Basalt	1200	750	0.35
3	Basalt-LL	Type I	325	Basalt	1225	700	0.45
4	Basalt-LH	Type I	325	Basalt	1225	700	0.55
5	Siliceous-LL	Type I	325	Siliceous	1225	700	0.45
6	Siliceous-LH	Type I	325	Siliceous	1225	700	0.55

Concrete mixes Basalt-HL and Basalt-HH were mixed with sikament-320 super plasticizer.

Experimental Work

The present experimental investigation was carried out for the different concrete mix cases shown in Table 2 for determining the individual strengths; namely, compressive strength of cylinders f_c, flexural strength f_f, shear strength f_s and splitting tensile strength f_t, of a blended preset concrete for different blend ratios r at different time lags t ($0 < t < 1.5\ t_i$). The used blend ratios r in the present investigation are (blend ratio r= weight of preset concrete/ weight of fresh concrete) as: $r = 0, 1, 5, 10$ and ∞ .

The time lags considered are: t = 0.0, 0.4, 0.7, 1.0 and 1.5 of the initial setting time; where initial and final setting times of the cement are shown in Table 1.

The experimental program mainly consists of two parts, *viz.*, preparation of the prescribed mixes and blends and testing of the prepared specimens. For this, standard cylinders of 15 cm diameter with 30 cm height and beams of overall dimension 15 cm ×15 cm × 70 cm have been used throughout the investigation. The prepared specimens have been tested under a universal testing machine.

The cylinder specimens were prepared and tested according to ASTM C 617-98, ASTM C39-01 and ASTM C873-99. Compressive strength was evaluated after 7 and 28 days, while splitting tensile and shear strengths after 28 days using a universal testing machine.

Flexural strength (ASTM C78-00) was measured after 28 days using beams spanning 600 mm and loaded at their third points using the computerized Universal Testing Machine. The flexural strength was calculated as the modulus of rupture of the beam. Splitting tensile strength was measured on one half of the failed beams and the other half was used for getting the shear strength (q = 1000 P / 2 * 15 * 15). Splitting tensile stress was calculated from the measured load using the following formula: $f_t = 2P / \pi bd$; where b and d are the breadth and depth of the beam, repectively.

RESULTS AND DISCUSSION

The experimental results of various strengths; compressive strength f_c, flexural strength f_f, splitting tensile strength f_t and shear strength f_s are presented in Tables 3 – 6 and Figs. 1-6.

The test results have been recorded for all mix types, for all blend ratios (r = 0, 1, 5, 10 and ∞) and for all time lags t (0.0, 0.4 t_i, 0.7 t_i, t_i and 1.5 t_i).

Table 3. Cylinder compressive strength for remixed and blended concrete at 28 days

Mix Type	Blend Ratio	f_c (kg/ cm^2) at time lag t =				
		0.0	0.4 t_i	0.7 t_i	t_i	1.5 t_i
Basalt-HL	1	576	622	642	581	557
	5		608	631	576	551
	10		595	612	570	527
	∞		588	600	563	521
Basalt-HH	1	522	558	582	531	501
	5		552	581	527	497
	10		542	576	522	489
	∞		531	570	516	473
Basalt-LL	1	395	443	461	421	387
	5		435	449	414	376
	10		421	441	408	368
	∞		408	428	388	354
Basalt-LH	1	341	380	410	353	331
	5		372	403	343	327
	10		360	381	328	318
	∞		347	372	315	312
Siliceous-LL	1	306	331	357	280	261
	5		325	338	268	249
	10		318	325	254	235
	∞		308	312	252	230
Siliceous-LH	1	253	281	298	246	213
	5		274	294	240	206
	10		268	288	232	202
	∞		255	266	219	185

Compressive Strength

Figures 1 and 2 as well as Table 3 show the relationship between compressive strength of self-mixing concrete and the relative time lag. The results given are for all considered mix types and for all blend ratios. It can be seen that compressive strength increases from zero time lag up to 0.7 t_i time lag, then decreases. For blend ratio of ∞ and type I cement, the maximum obtained strength increase ranges from 4% to 10% for basalt aggregate concrete, while the increase ranges from 2% to 5% for the siliceous aggregate concrete. The decrease in strength at relative time lag equal to 1.5 t_i is 8% to 10% for the basalt aggregate concrete while it is 25% to 27% for the siliceous aggregate concrete. This indicates that there exists a fundamental difference in the behavior of basalt and siliceous aggregates in remixed concretes. It can also be noted that no reduction in strength is recorded when remixing was undertaken before 0.7 times the initial setting time.

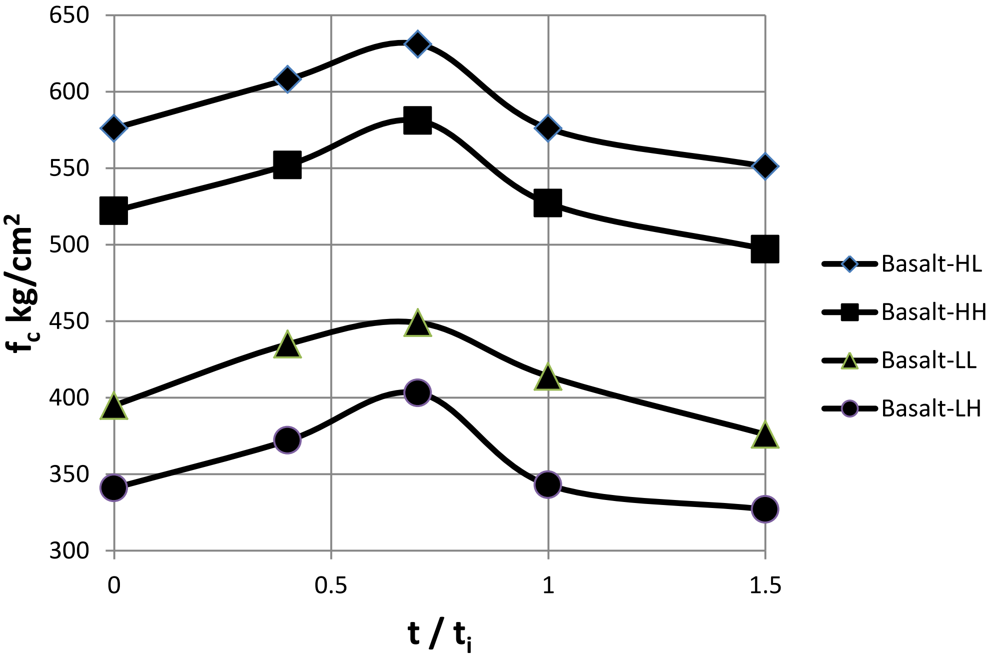

Figure (1): Variation of compressive strength of remixed and blended basalt concrete with time lag for blend ratio = 5

Blending the set concrete with fresh concrete with a blend ratio from 10 to 1 resulted in further strength increase over that obtained using remixing only as shown in Figure 3. The strength increase ranged from 1.5% to 11% at 0.7 t_i time lag for the basalt concrete and 13% to 15% for the siliceous concrete. At 1.5 t_i time lag, the basalt concrete had an increase in strength of 5% to 8%, while the siliceous concrete had an increase of strength of 10% to 11%. The increase in strength appears to be more pronounced for the siliceous aggregate concrete than the basalt aggregate concrete.

Flexural Strength

Figure 4 and Table 4 show the relationship between flexural strength and the relative time lag for r=5. It can be seen that flexural strength behaves similar to the corresponding compressive strength; where it increases relative to time lag of 0.7 t_i, then decreases. For blend ratio of ∞ and type I cement, the maximum obtained strength increase ranges from 7% to 12% for basalt aggregate concrete, while the increase was 13% for the siliceous aggregate concrete. The decrease in strength at relative time lag equal to 1.5 t_i is 7% to 12% for the basalt aggregate concrete, while it is 22% for the siliceous aggregate concrete. This, again, indicates that there exists a fundamental difference in the behavior of basalt and siliceous aggregates in remixed concretes.

Blending the set concrete with fresh concrete with a blend ratio from 10 to 1 resulted in further increase in flexural strength over that obtained using remixing only. The strength increase ranged from 7% to 11% at 0.7 t_i time lag for the basalt concrete and 10% for the siliceous concrete. At 1.5 t_i time lag, the basalt concrete had an increase in strength of 5% to 13%, while the siliceous concrete had an increase of strength of 10%.

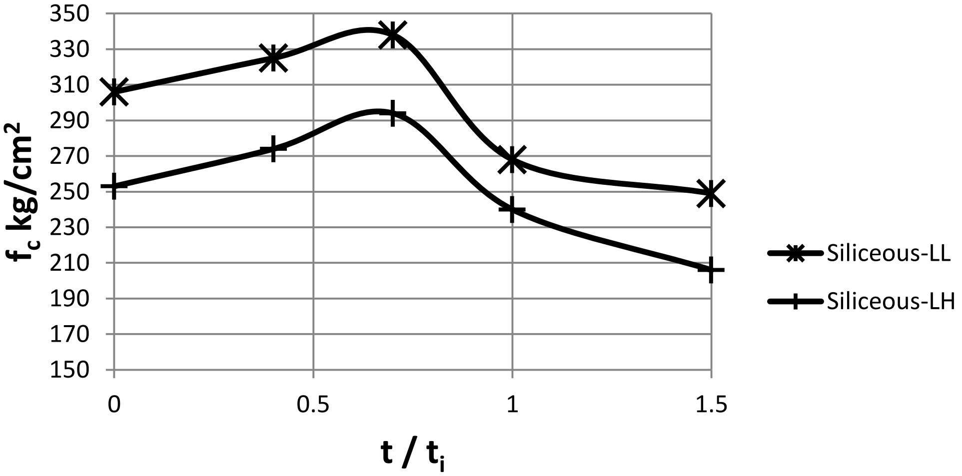

Figure (2): Variation of compressive strength of remixed and blended siliceous concrete with time lag for blend ratio = 5

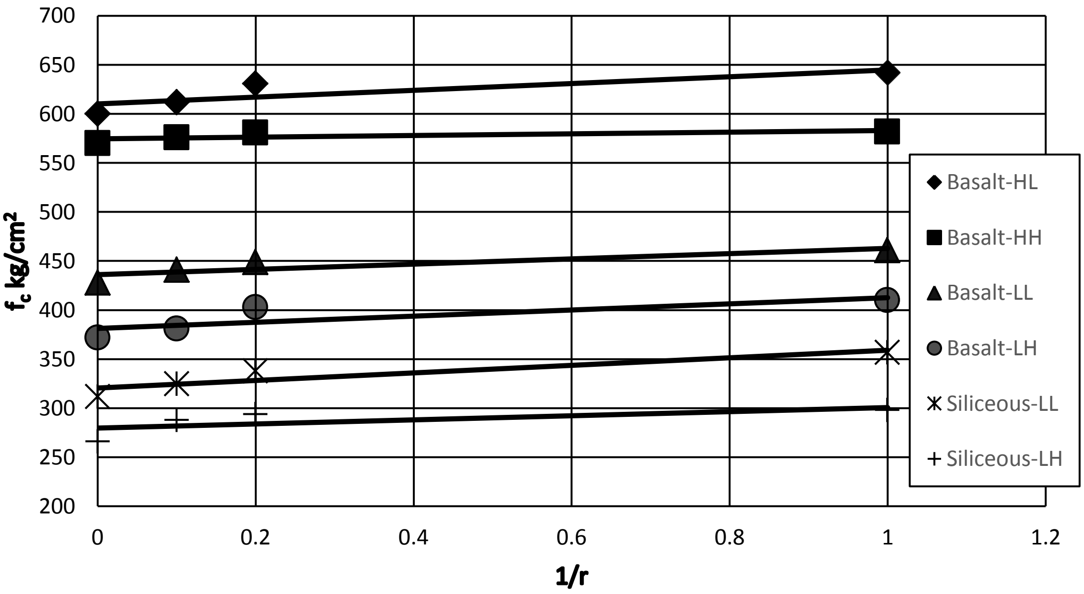

Figure (3): Variation of compressive strength of remixed and blended concrete with inverse blend ratio at time lag = 0.7 t_i

Table 4. Flexural strength for remixed and blended concrete at 28 days

Mix Type	Blend Ratio	ff (kg/ cm^2) at time lag t =				
		0	0.4 t_i	0.7 t_i	t_i	1.5 t_i
Basalt-HL	1	67.5	76.7	80.2	72.6	68.6
	5		75.7	77.5	71.6	66.6
	10		72.4	75.9	70.6	65.4
	∞		69.4	74	68.9	63.5
Basalt-HH	1	63.8	70.2	72.8	66.6	62.8
	5		68.9	71.1	65.9	62.4
	10		66.9	69.6	65.2	59.3
	∞		66.7	68.4	62	59
Basalt-LL	1	54.4	60.9	64.9	58.7	55
	5		60.1	63	56.9	54.2
	10		58.7	61.1	53.3	51.4
	∞		57.1	60.2	52	47.7
Basalt-LH	1	45	51.8	56.1	49.6	44.2
	5		50	55.3	48.5	42.5
	10		48.4	51.4	46.4	41.1
	∞		46.7	50.6	44.1	40.1
Siliceous-LL	1	43.1	50.9	53	42.3	37.5
	5		49	52.1	41.8	36.2
	10		47.8	51.2	41	35.1
	∞		45.9	48	40	34.1
Siliceous-LH	1	37.5	44.7	46.2	37.2	32.8
	5		43.3	45.8	36.9	31.8
	10		42	45	36	31.1
	∞		40.3	42.4	34.7	29.1

Splitting tensile Strength

Figure 5 and Table 5 show the results for splitting tensile strength. It can be seen that tensile strength behaves similar to the corresponding compressive strength; where it increases relative to time lag of 0.7 t_i, then decreases. For blend ratio of ∞ and type I cement, the maximum obtained strength increase ranges from 3% to 6% for basalt aggregate concrete with high cement content and 8% to 10% for lower cement content. The increase was 5% to 6% for the siliceous aggregate concrete. The decrease in strength at relative time lag equal to 1.5 t_i is 4% to 6% for the basalt aggregate concrete, while it is 7% to 9% for the siliceous aggregate concrete.

Blending the set concrete with fresh concrete with a blend ratio from 10 to 1 resulted in further increase in tensile strength over that obtained using remixing only. The strength increase at 0.7 t_i time lag ranged from 4%

to 7% for the basalt concrete with high cement content and 11% to 20% at lower cement content. The increase in tensile strength at the same time lag was 9% to 14% for the siliceous concrete. At 1.5 t_i time lag, the basalt concrete had an increase in strength of 3% to 5% for higher cement content and 9% to 13% at lower cement content. The siliceous concrete had an increase of strength of 14% to 16%.

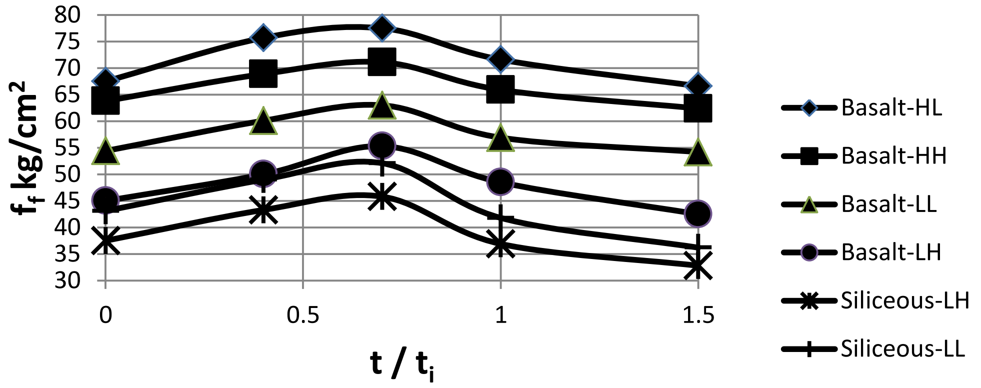

Figure (4): Variation of flexural strength of remixed and blended concrete with time lag for blend ratio = 5

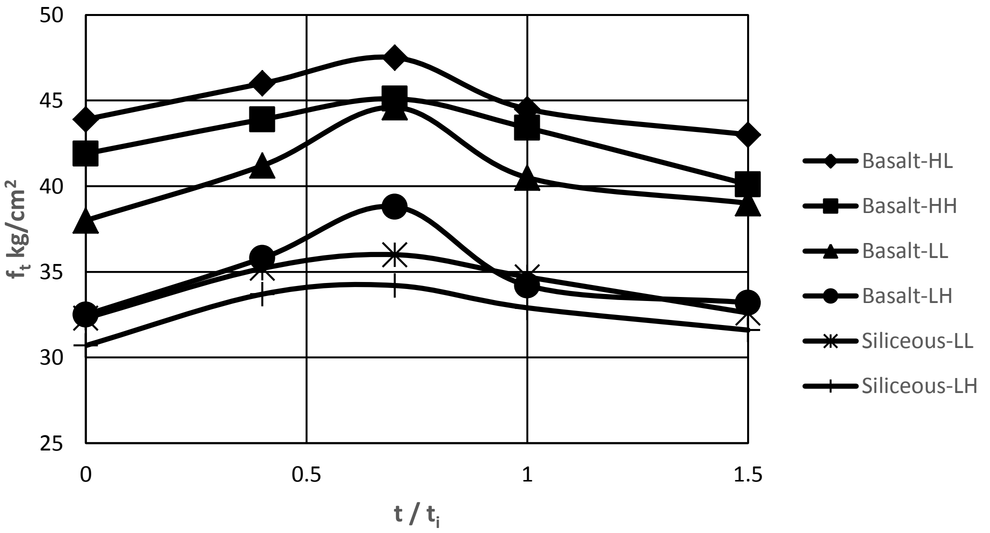

Figure (5): Variation of split tensile strength of remixed and blended concrete with time lag for blend ratio = 5

Table 5. Splitting tensile strength for remixed and blended concrete at 28 days

Mix Type	Blend Ratio	f_t (kg/ cm^2) at time lag t =				
		0.0	0.4 t_i	0.7 t_i	t_i	1.5 t_i
Basalt-HL	1	43.9	46.5	48.2	44.9	44
	5		46	47.5	44.5	43
	10		45.9	47	44.2	42.4
	∞		45	46.6	43.3	41.5
Basalt-HH	1	41.9	45.1	46.1	44.2	40.6
	5		43.9	45.1	43.4	40.1
	10		42.9	44.8	40.7	39.7
	∞		42.3	43.3	40.5	39.6
Basalt-LL	1	38	43.1	46	41.9	40.7
	5		41.2	44.6	40.5	39
	10		39.2	43	38.5	36.7
	∞		38.9	41.6	37.3	35.7
Basalt-LH	1	32.5	37.2	41.7	35.3	34.3
	5		35.8	38.8	34.2	33.2
	10		34.3	36.2	33.7	32
	∞		33.4	35.2	32.9	31.3
Siliceous-LL	1	32.3	36.3	38.4	37.1	35.1
	5		35.2	36	34.7	32.6
	10		34.7	35.4	33.3	31.5
	∞		33.2	34.2	32	30.3
Siliceous-LH	1	30.7	34.1	35	33.5	32.2
	5		33.7	34.2	32.9	31.6
	10		32.3	32.9	31.4	30.1
	∞		31.4	32.3	29.9	28.1

Shear Strength

Figure 6 and Table 6 show the results for shear strength. It can be seen that shear strength behaves similar to the corresponding compressive strength; where it increases relative to time lag of 0.7 t_i, then decreases. For blend ratio of ∞ and type I cement, the maximum obtained strength increase ranges from 1% to 4% for basalt aggregate concrete, while the increase is 5% for the siliceous aggregate concrete. The decrease in strength at relative time lag equal to 1.5 t_i is 2% to 4% for the basalt aggregate concrete with lower w/c ratio, while it is 13% to 14% for the basalt concrete with higher w/c ratio. The decrease of shear strength is 1% to 2% at relative time lag equal to 1.5 t_i for the siliceous aggregate concrete.

Blending the set concrete with fresh concrete with a blend ratio from 10 to 1 resulted in further increase in shear strength over that obtained using remixing only. The strength increase ranged from 5% at lower w/c ratio to 8% at higher w/c ratio at 0.7 t_i time lag for the basalt concrete. The strength increase was 4% at lower w/c ratio and 11% at higher w/c ratio for siliceous concrete. At 1.5 t_i time lag, the basalt concrete at lower w/c ratio had an increase in strength of 2% to 3% and 5% to 15% at higher w/c ratio. The siliceous concrete had an increase of strength of 5% at lower w/c ratio and 11% at higher w/c ratio.

General Discussion

The concrete is a composite material, where its strength depends on the properties of its matrix, the coarse aggregate embedded in it and the interface between these two materials. The remixing process may affect the properties of the matrix and the interface, while the properties of the aggregate remain unaffected. Remixing may affect the properties as follows:

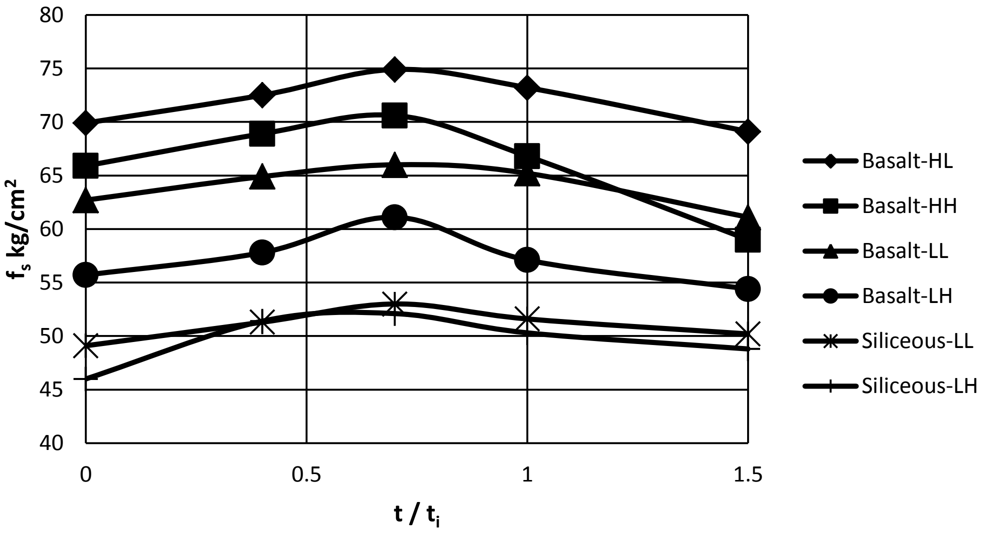

Figure (6): Variation of shear strength of self- mixes blend concrete with time lag for blend ratio = 5

Table 6. Shear strength for remixed and blended concrete at 28 days

Mix Type	Blend Ratio	f_s (kg/ cm^2) at time lag t =				
		0.0	0.4 t_i	0.7 t_i	t_i	1.5 t_i
Basalt-HL	1	69.9	73.6	75.9	74	69.4
	5		72.5	74.9	73.2	69.1
	10		71.8	73.7	70.8	68.3
	∞		71.3	72.8	69.6	68.2
Basalt-HH	1	65.9	70	71.7	67.8	59.7
	5		68.9	70.6	66.8	59
	10		67.2	68.8	64.2	57.6
	∞		65.8	66.8	62.6	56.8
Basalt-LL	1	62.7	65.7	66.9	65.3	61.4
	5		64.9	66	65.2	61.1
	10		63.9	64.9	62.6	60.1
	∞		62.9	64.2	61.4	59.9
Basalt-LH	1	55.7	59	61.5	57.9	56.8
	5		57.8	61.1	57.1	54.4
	10		56.3	57.2	54.3	51.1
	∞		55.9	56.8	53.7	48.7
Siliceous-LL	1	49.1	52.3	53.7	52	50.5
	5		51.3	53	51.6	50.2
	10		50.9	51.6	51.1	48.8
	∞		50.2	51.3	50	48.3
Siliceous-LH	1	46	51.8	53.5	52	50.8
	5		51.4	52.1	50.3	48.8
	10		49.2	50	48	46.9
	∞		47.4	48.5	46.3	45.5

Physical Effects

1. Allowing the redistribution of the mixing water by remixing in the presence of fresher concrete.
2. Reducing the voids in the concrete by remixing.
3. Achieving a more uniform structure of the resulting concrete.
4. Improving the interface between the aggregate particles and the matrix by remixing, resulting in breaking the weak bonds and allowing new stronger ones to develop.
5. Removing the initial cracking due to initial volume changes.

Chemical Effects

1. The supply of fresher concrete during the dormant period results in temperature increase which may affect the hydration process.
2. The reshaping of the gel by remixing allows simpler access of the water to the unhydrated part of the cement.

CONCLUSIONS

The following conclusions are based on the results of the current investigation:

1. Remixing can improve the strength of concrete, provided that it is performed within a period not exceeding 0.7 the initial setting time of the cement.
2. Blending the remixed concrete with fresh concrete improves the strength if the remixing is delayed beyond 0.7 the initial setting time of the cement.
3. The flexural, tensile as well as shear strengths also benefit from remixing.
4. The increase of compressive strength of concrete using basalt aggregate by remixing is higher than using siliceous aggregates in case no fresh concrete is added. Upon adding fresh concrete, the siliceous aggregate concrete benefits more than the basalt aggregate concrete.
5. The tensile strength of the concrete mixes with lower cement content benefits by remixing more than those with higher cement content.
6. The shear strength of the concrete mixes with higher w/c ratios benefits by self-mixing more than those with lower w/c ratios.

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