Estimation of fresh concrete temperature

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Abstract. ACI Committee 305 R proposed an equation for estimating temperature of fresh concrete with ice or without ice. Upon using the equation, it is shown that it is inaccurate. When using ice in percentage greater than 50 % of the mixing water , that equation gives irrational results. Also, ACI Equation under-estimates the actual temperature and it can be used with a little accuracy when using ice as a percentage of added mixing water at 20 % and lower. For more accuracy and rational results and at different percentages of ice to replace mixing water, an experimental test and theoretical analysis have led to a more accurate equation for estimating fresh concrete temperature.

Keywords: **Heat of Hydration, Fresh Concrete, Temperature, Ice, mixing water.**

تخمين درجة حرارة الصب للخرسانة الطرية

الخلاصة اللجنة (305R) في معهد الخرسانة الأمريكي (ACI) اقترحت معادلة لتخمين درجة حرارة الخرسانة الطرية عند استعمال الثلج لتعويض ماء الخلط أو بدونه . عند استعمال هذه المعادلة تبين أنها غير دقيقة حيث عند استعمال الثلج بنسبة اكبر من 50 % من ماء الخلط تعطي هذه المعادلة نتائج غير منطقية . كذلك فإنها تعطي نتائج اقل من نتائج درجات الحرارة الطبيعية للخرسانة الطرية، و يمكن استعمالها بدقة قليلة عندما يكون الثلج الذي يعوض ماء الخلط بنسبة 20 % أو اقل. و لغرض الحصول على نتائج أكثر دقة و منطقية عند استعمال الثلج الذي يعوض ماء الخلط بنسب مختلفة ، تم إجراء اختبارات عملية و تحليل نظري لنماذج و الذي أدى إلى اقتراح معادلة أكثر دقة لتخمين درجة حرارة الخرسانة الطرية.

1- Introduction:

The properties of hardened concrete such as : strength, durability, porosity and dimensional stability greatly depend on the initial conditions of the formation, i.e. depend on initial production of fresh concrete. Also, the properties of fresh concrete depend on many factors like, proportioning, temperature of ingredients, ambient temperature, w/c ratio, cement type, admixture type, and others [1].

All these factors effect on the heat of hydration that liberates instantaneously after mixing water with cement. Since the main compounds of cement : C_3S, C_2S, C_3A and C_4AF are non-equilibrium compounds because of having high reactions temperatures, the adding of water to these compounds will liberate a heat in order to reach the stable state of low energy [1].

On mixing and placing concrete at hot weather, the heat of hydration will effect on the properties of fresh concrete and hardened concrete later. Heat of hydration besides ambient high temperature will accelerate the evaporation of mixing water during few minutes after the hydration began. This will contribute to form a porous compound contains different types and sizes of voids which leads to reduce concrete strength at early ages and effect the durability and dimensional stability later [2, 3, 4].

So, the controlling of the fresh concrete temperature is very important to improve the concrete properties.

1:1- Heat of Hydration:

On mixing water with cement, high and large amount of heat of hydration will liberate during few minutes reach to 6 cal/gm/hr, this may be because of solution of aluminates and sulfates. Then the heat will decrease to lowest value (less than 1 cal/gm/hr) during (45 – 60) minutes. After (4- 8) hours, heat of hydration will rise again up to 3 cal/gm/hr (0.05 cal/gm/min.) due to reactions form ettringite and calcium – silicate – hydrates (C-S-H). So, at that time the hydrated cement paste will lose its plasticity and begin to set. Finally, the final composition of hydrated cement paste (hcp) will form the concrete composition and this depends on the rate of heat of hydration liberation and its amount just after mixing water with cement [1].

In order to control heat liberation, it is very important to control the temperature of concrete ingredients. Regarding aggregate represents high percentage of concrete ingredients (75 – 80)%. So, reducing 1 C of its temperature can reduce fresh concrete temperature by (0.5 C) [2,3].

In spite of water represents low percentage of concrete ingredients (7 – 8) %, but, its high specific heat (which it reaches five times the specific heat of aggregate) can contribute to reduce fresh concrete temperature by (0.5 C) when reducing (2C) of its temperature [2,3]. Also, reducing water temperature is more significant than reducing aggregate temperature because aggregate loses the temperature fastly as being solid.
By using ice as a part of mixing water which can contribute to reduce fresh concrete temperature greatly. The use of 50 % ice by weight of mixing water can lower (11 C) of fresh concrete temperature through melting alone, while the resulting cold water would have an additional cooling by (4 C) in hot weather [2,5].
So, by using ice as a part of mixing water is greatly effective to reduce fresh concrete temperature because on melting ice alone, it absorbs 79.6 cal/gm of heat [1].

1:2- ACI Committee Equations :

ACI Committee 305 R [1] proposed the following equation to estimate fresh concrete temperature when using ice as a part of mixing water :

$$T_f = \frac{0.22\,(TaWa + TcWc) + (Ww - Wi)\,Tw + TaWwa - 79.6\,Wi}{0.22\,(Wa+Wc) + Ww + Wi + Wwa} \qquad (1)$$

Then, the Committee [2] adopted another equation to estimate fresh concrete temperature when using ice as a percentage of added mixing water regarding of the temperature of ice :

$$T_f = \frac{0.22\,(TaWa + TcWc) + TwWw + TaWwa - Wi\,(79.6 - 0.5\,Ti)}{0.22\,(Wa+Wc) + Ww + Wi + Wwa} \qquad (2)$$

where :
T_f = temperature of fresh mixed concrete (C).
T_a , T_c , T_w , T_i = temperatures of aggregate, cement, mixing water and ice respectively (C).
W_a , W_c ,W_w , W_{wa} , W_i = weight of aggregate, cement, mixing water, free water on aggregate and ice respectively (C).
Theoretically, in a mix consists of 3640 gm cement at 20 C, 18760 gm aggregate at 20 C, 2000 gm water, if percentage of mixing water is replaced by ice. Then, calculating fresh concrete temperature (T_f) at different percentages of ice and at different water temperature, let percentages of ice be (0.6, 0.7, 0.8, 0.9), ice temperature is at 0 C (at melting point). This leads to the results shown in Table (1) and Fig.(1)

Table (1): Fresh concrete temperature at different percentages of ice and different water temperature upon using ACI Eq.(1)

percentage of ice							
0.6		*0.7*		*0.8*		*0.9*	
T_w (C)	T_f (C)	T_w (C)	T_f (C)	T_w (C)	T_f (C)	T_w (C)	T_f (C)
30	*-1.30*	*30*	*-5.32*	*30*	*-9.35*	*30*	*-13.38*
20	*-0.72*	*20*	*-4.17*	*20*	*-7.62*	*20*	*-11.07*
10	*-0/13*	*10*	*-3.01*	*10*	*-5.89*	*10*	*-8.76*
5	*0.15*	*5*	*-2.43*	*5*	*-5.02*	*5*	*-7.61*

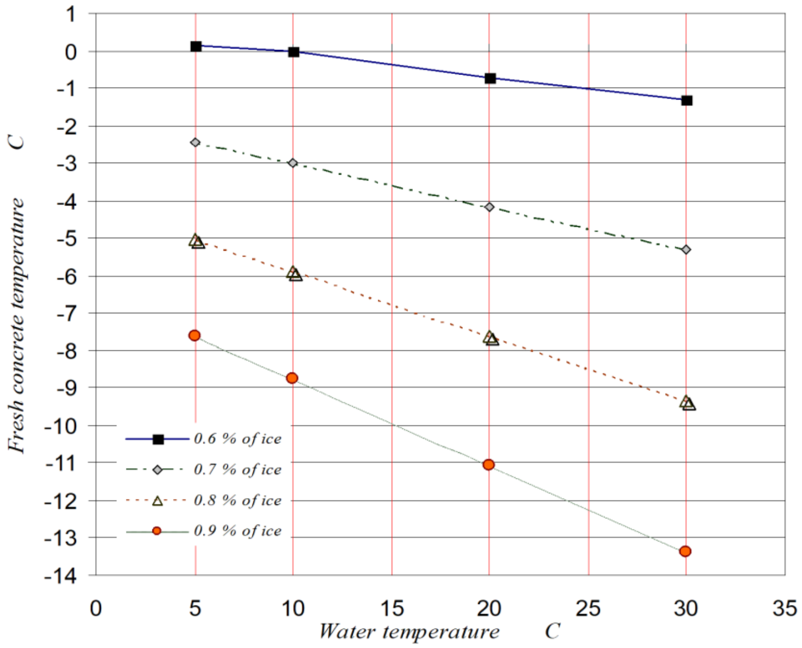

Fig.(1): Effect of using ice in percentage greater than 50 % of mixing water on fresh concrete temperature on using ACI Eq.(1)

Thus, by Eq. (1), the temperature of fresh concrete is increased as the water temperature decreases, and this is not rational result.

2 - Experimental Work :

The work consists of mixing the following ingredients (3640 gm ordinary Portland cement at 34 C, 7920 gm sand at 34 C, 10480 gm round gravel at 34 C, 2000 gm crushed ice or crushed ice with water at different temperatures).

Crushed ice is added at different percentages in the mixtures (at 100, 80, 60, 50, 40, 20, 0) % of mixing water, the mixing time was (1- 3) minutes (depending on melting of crushed ice), the temperature of fresh mixed concrete was measured after (3, 8, 15) minutes after mixing, it was almost constant during these periods. Also the fresh temperature is measured for other mixtures without ice at different water temperatures. The results shown in Table (2) and Fig. (2) :

Table (2): A comparison among actual temperature and those calculating from Eq.(1) and Eq.(3) for different percentages of ice that replacing mixing water

T_a C	T_c C	water		ice		actual T_f C	proposed T_f C	ACI(1) T_f C	ACI(2) T_f C	Remarks
		W_w gm	T_w C	W_i gm	%					
34	34	-	-	2000	100	11	14.84	1.20	1.20	w/c = 0.55 Ww = 2000 gm Wc = 3640 gm Ws = 7920 gm Wg = 10840 gm Wa = 1876 gm period of mixing = (1 – 3) min.
34	34	400	15	1600	80	16	17.93	3.20	6.70	
34	34	800	15	1200	60	20	20.83	9.50	12.10	
34	34	1000	14	1000	50	22	22.20	12.70	14.70	
34	34	1200	15	800	40	24	23.55	15.86	17.60	
34	34	1600	15	400	20	26	26.10	22.20	23.10	
34	34	2000	15	0	0	29	28.52	28.52	28.52	
34	34	2000	37	-	-	36	34.87	34.87	34.87	
34	34	2000	30	-	-	34	32.85	32.85	32.85	
34	34	2000	20	-	-	31	29.96	29.96	29.96	
34	34	2000	10	-	-	28	27.07	27.07	27.07	

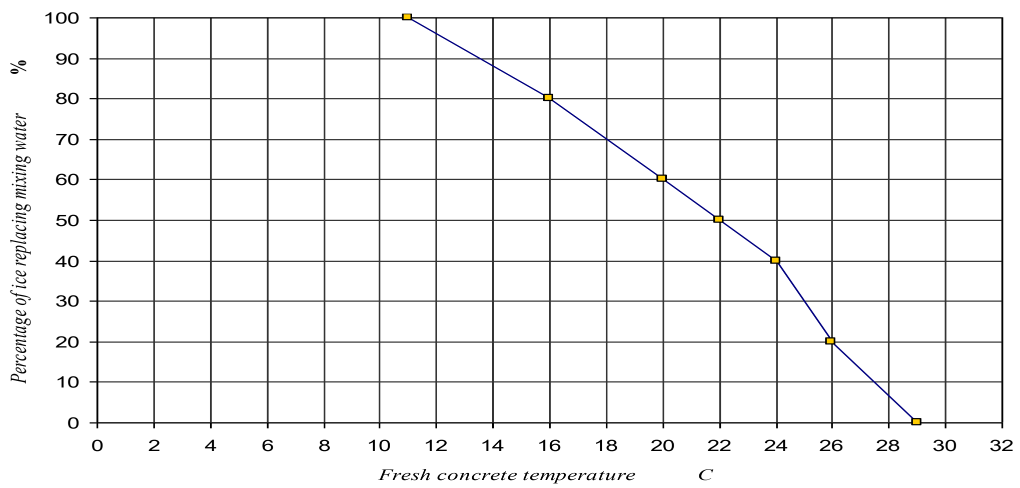

Fig.(2): Effect of using ice in different percentage on concrete temperature

3- **Theoretical Analysis**:

When analyzing the results from Eq.(1), it is found that it gives irrational results when using ice in percentage greater than 50 % of mixing water. Beside it underestimates the actual results, also it can be used with a little accuracy when using ice at 20 % and lower.

The analysis of the actual results of fresh concrete temperature and considering of different percentages of ice up to 100 % to replace mixing water leads to a modified equation which is proposed as follows :

$$T_f = \frac{0.22\,(TaWa + TcWc) + Tw\,Ww + TaWwa - 39.8\,Wi}{0.22\,(Wa+Wc) + Ww + Wwa + 0.5\,Wi} \qquad (3)$$

Where the value (39.8 = 79.6 × 0.5) results from using specific heat of ice and 79.6 is related to the heat of fusion necessary to melt ice alone.

0.22 = specific heat of aggregate and cement which is equivalent values .

The specific heat of ice at 0 C is about 2.1 j/gm.k, the specific heat of water at 25C is about 4.186 j/gm.k. So, when using crushed ice at melting point (0 C), then turn into water at 0 C, the absorbed heat will depend on the relative specific heat of the ice melting to water and this will be the ratio of specific heat of ice to specific heat of water (2.1/4.186 = 0.5). Therefore, the 0.5 factor used in Eq.(3) represents that. Thus, the absorbed heat due to melting ice that is used in the mix is equal to (79.6 × 0.5=38.8).

$$T_a = \frac{T_s\,Ws + Tg\,Wg}{Ws + Wg} \qquad (4)$$

when T_s differs from T_g , T_a , where:

T_s , T_g = temperature of fine aggregate and coarse aggregate respectively.

W_s , W_g = weight of fine aggregate and coarse aggregate respectively.

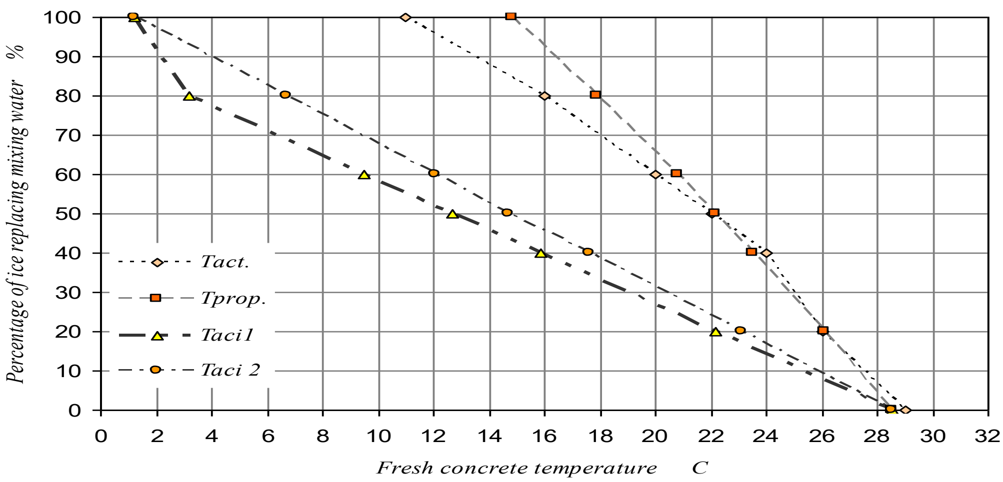

Fig.(3): A comparison among actual fresh concrete temperature and those calculated from Eq.(1) , Eq.(2) and Eq.(3)

The proposed equation Eq.(3) gives rational results unlike ACI Eq.(1). Beside it gives results approach the actual temperature of fresh concrete as shown in Fig.(3) which shows a comparison among actual temperature of fresh concrete and those calculated from Eq. (1) and Eq. (3).

Also proposed equation, Eq.(3) can be used to different w/c ratio with a high accuracy as illustrated in Table (3) which represents a comparison among actual temperature of fresh concrete and the one calculated by Eq. (1) and Eq. (3) for different weights and temperatures of ingredients as well as different percentage of ice replacing mixing water.

The percentage of difference between the actual temperature and the one calculated by the proposed equation Eq.(3) when using ice at percentage less than 50% of mixing water approach zero. While the difference is (0.9 – 4)% when using ice at (50 – 80) % , and at (80 – 100)% of ice to replace mixing water, it gives (12 – 30) % results higher than the actual fresh concrete temperature. That leads to the proposed equation is more accurate than ACI equations (1) and (2) to estimate fresh concrete temperature.

Table (3) : A comparison among actual temperature of fresh concrete and those calculated from ACI equation (Eq. 1) and proposed equation (Eq. 3) for different mixes

w/c %	*Aggregate*		*Cement*		*Water*		*Ice*		*Actual T_f C*	*Prop. T_f C*	*ACI T_f C*
	W_a kg	*T_a C*	*W_c kg*	*T_c C*	*W_w kg*	*T_w C*	*W_i kg*	*%*			
63	78.5	2	13.7	24	0	-	8.60	100	1	- 9.60	- 20.03
62	72.7	2	12.3	10	0	-	7.60	100	0	- 10.82	- 20.76
33	70.0	11	24.0	34	0	-	7.80	100	4	1.40	- 9.55
40	64.0	17	17.0	33	0	-	6.65	100	5	4.64	- 6.81
62	91.3	24	16.0	24	1.62	21	8.30	84	7	9.20	- 6.99
62	87.0	22	15.2	23	0	-	9.40	100	7	4.55	- 9.22
33	70.0	33	24.0	34	0	-	7.80	100	13	13.25	2.35
62	155.0	32	27.5	32	1.50	15	15.50	91	12	13.98	- 3.22
55	155.1	30	30.1	32	3.00	25	13.50	82	13	15.31	- 1.77
62	79.1	27	13.3	25	4.30	6	4.00	48	17	15.40	7.91
62	79.1	28	13.3	29	3.35	12	4.90	60	17	15.97	5.72
55	150.0	32	27.5	32	4.00	25	11.00	73	17	18.78	3.68
33	120.0	36	40.0	36	0	-	13.00	100	17	18.04	4.91
40	144.3	35	38.0	36	0	-	14.80	100	17	17.22	4.11
33	70.0	23	24.0	34	3.80	12	4.00	51	18	14.80	7.48
55	129.0	36	28.0	34	5.00	23	10.30	67	18	21.11	6.11
55	155.1	28	30.1	28	10.50	25	6.00	36	20	21.47	13.55
40	144.3	35	38.0	35	6.30	15	8.60	58	21	22.80	12.45
62	158.1	24	26.7	23	16.53	20	0	0	25	25.10	25.10
33	70.0	32	24.0	34	7.80	12	0	0	30	26.90	26.90
40	144.3	33	38.0	33	15.20	22	0	0	30	29.98	29.98
55	155.1	32	30.0	32	16.50	30	0	0	34	31.42	31.42
62	155.0	33	27.5	32	17.00	31	0	0	34	32.30	32.30
40	144.3	33	38.0	33	15.20	55	0	0	40	39.05	39.05
62	155.0	32	27.5	32	17.00	57	0	0	41	39.43	39.43
53	129.0	33	28.7	34	15.20	55	0	0	42	39.83	39.83

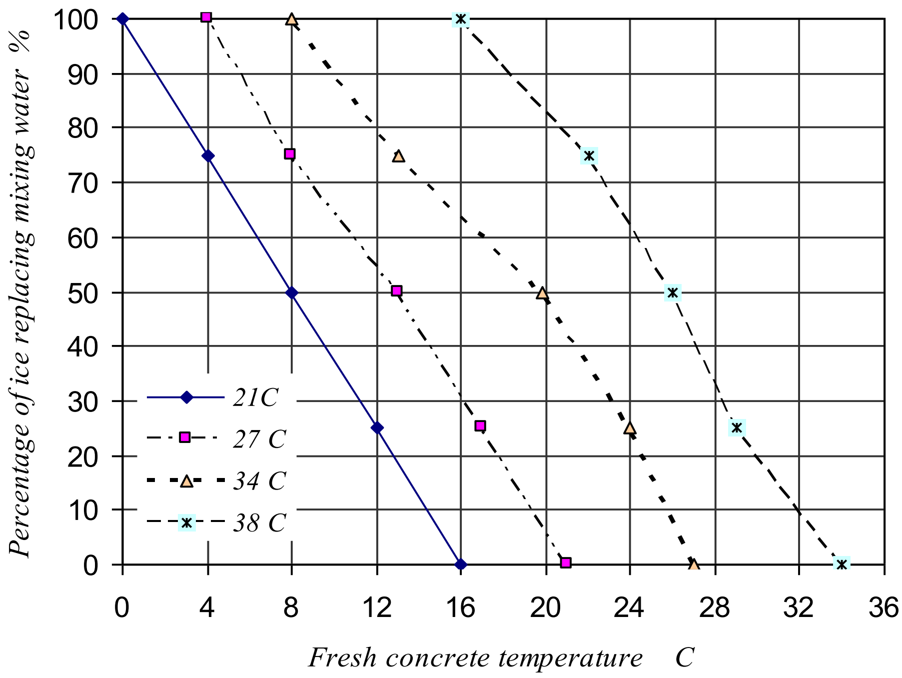

Fig.(4) : Effect of percentage of ice replacing mixing water on fresh concrete temperature

Fig.(4) illustrates the effect of using percentage of ice replacing mixing water on fresh concrete temperature. It can be seen that when all other ingredients are at (21,27,34,38) C, the 10 % replacement of water by ice leads to concrete temperature decrease of (1.7, 1.9, 1.9, 2.0) C respectively. This means the percentage of ice used in mixing concrete will lower its temperature more for higher concrete temperature than for lower one. For 38 C concrete temperature, there is 19.8 C reduction in the resulting concrete temperature on using crushed ice at 100 %, while for 16 C concrete temperature, there is 16 C reduction in the resulting concrete temperature on using crushed ice at 100 % ,too. So, the use of crushed ice in concrete mixture to replace mixing water has benefits in cooling of fresh concrete temperature to a certain limits.

Fig.(5) represents a comparison among fresh concrete temperatures on using Eq.(1), Eq.(2) and a proposed equation Eq.(3) at different percentage of ice replacing mixing water. It shows that the temperature calculated by proposed equation approach the actual one. While the temperature calculated by ACI equation differs highly when percentage of ice is greater than 20 %.

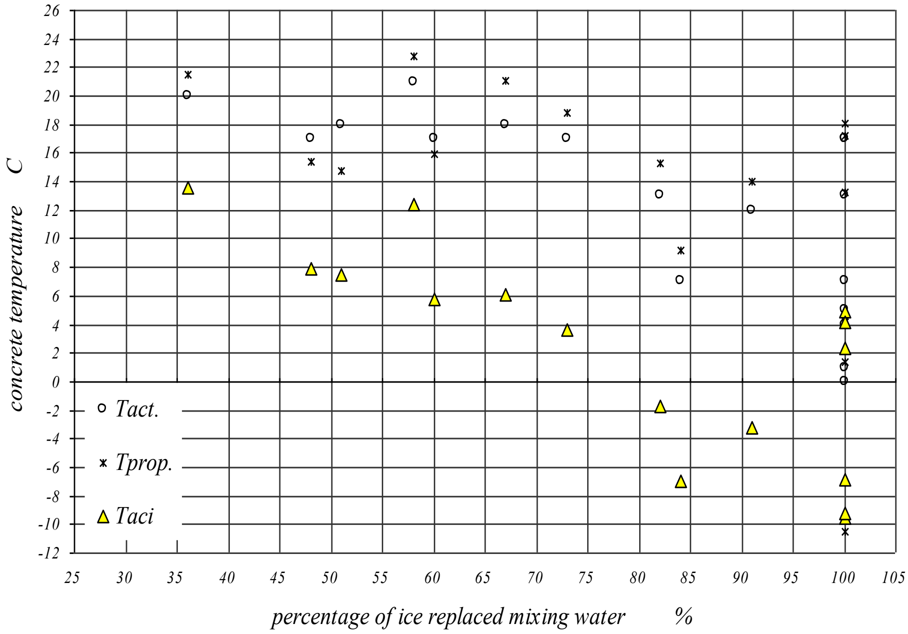

Fig.(5): A comparison among the temperature of fresh concrete at different percentage of ice replacing mixing water

4 - Conclusions:

1. The percentage of ice used in mixing concrete will lower its temperature more for higher concrete temperature than for lower one.
2. The use of crushed ice in concrete mixture to replace mixing water has benefits in cooling of fresh concrete temperature to a certain limits in order to improve the properties of concrete in hot conditions.
3. The percentage of ice used in mixing concrete lowers its temperature more for higher concrete temperature than for lower one.
4. ACI Committee 305R equation for estimating fresh concrete temperature is inaccurate. When using ice in percentage greater than 50 % of mixing water, it gives irrational results. Also, this equation underestimates the actual temperature when using ice at 20 % or less of mixing water.
5. A modified equation for estimating fresh concrete temperature is proposed, Eq.(3) has proved to be more accurate in predicting fresh concrete temperature (T_f) :

$$T_f = \frac{0.22\,(TaWa + TcWc) + Tw\,Ww + TaWwa - 39.8\,Wi}{0.22\,(Wa+Wc) + Ww + Wwa + 0.5\,Wi}$$

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