19-21 May 2011, EPOKA University, Tirana, ALBANIA.

Development of Statistical Model, Mixture Design, Fresh and Hardened Properties of Furnace Slag - Lightweight Self Consolidating Concrete (FS-LWSCC)

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ABSTRACT

A response surface method was carried out to model the influence of key mixture parameters on properties affecting the performance of Expended Furnace Slag - Lightweight Self Consolidating Concrete (FS-LWSCC). Three key parameters that have significant influence on mixture characteristics of LWSCC were selected to derive mathematical model for evaluating the concrete fresh and hardened properties. Experimental levels of the variables (maximum and minimum) water/binder ratio (0.30 to 0.40), HRWRA (SP) (0.3 to1.2% by total content of binder), and total binder content (410 to 550kg/m^3) were used for the design of Furnace Slag-LWSCC mixtures. A total of 18 mixtures were designed and produced. The responses of the derived statistical model were slump flow, V-funnel flow time, J-Ring flow, J-Ring height difference, L- box, filling capacity, bleeding, air content, initial and final setting time, sieve segregation test, fresh unit weight, 28 days air dry unit weight, 28 days oven dry unit weight, and 7 and 28 days compressive strengths. It was seen that the proposed mix design model is a useful tool to understand the interactions between mixture parameters affecting important characteristics of Expanded Furnace Slag - LWSCC. This understanding might be simplified the mix design process and the required testing, as the model identifies the relative significance of each parameter, therefore providing important information required to optimize the mix design. Consequently, minimize the effort needed to optimize LWSCC mixtures ensuring balance between parameters affecting fresh and hardened properties.

Keywords: *lightweight self consolidating concrete, furnace slag, lightweight aggregates, mixture design*

1. INTRODUCTION

During the last few years, significant improvements have been achieved in terms of rheological and mechanical characteristics of concrete, particularly in self-consolidating concrete (SCC). Since SCC was introduced, different types of SCCs have been developed to meet the builders' requirements. Among these types is the concept of lightweight SCC (LWSCC).

For over 100 years structural lightweight aggregate concrete (LWC) has been widely used as building component worldwide. The density of structural LWC typically ranges from 1400 to 2000 kg/m^3 [1]. The use of lightweight aggregates in concrete can result in multiple advantages including, lower thermal connectivity, and maximized heat and sound insulation properties due to air voids existed in lightweight aggregate. Furthermore, Topcu [2] reported that the reduction in the dead weight of a building by the use of lightweight concrete could lead to a considerable decrease in the cross section of steel reinforced columns, beams, plates and foundation. It is also possible to reduce steel reinforcement and increase cost savings. LWAC may be produced by using either natural lightweight aggregates such as pumice, scoria, and diatomite, or by using artificial lightweight aggregates, which can be produced by heating clay, shale, slate, perlite, and vermiculite or cooling blast-furnace slag.

Despite of the above mentioned advantages and the increase demand of LWSCC worldwide, there are still many difficulties such as mix designs, segregation of coarse aggregate, density stability and compressive strength are not as great as normal weight SCC. In practice, as lightweight aggregates often have lower particle densities than the density of the mortar matrix in concrete, unbalanced density of the mixture can lead to an upward segregation of the coarse aggregates. This is opposite to conventional concrete with normal weight aggregates, where coarse aggregates may sink to the bottom in unbalanced mixture.

This study focuses on developing mix design model for FS-LWSCC and further understands the relationship between factors affecting important characteristics of Furnace Slag - LWSCC. Therefore, simplify the optimization process of LWSCC mixtures ensuring balance between parameters affecting workability and hardened properties.

2. EXPERIMENTAL PROGRAM

2.1 Materials, mix proportions and casting of specimens

2.1.1 Materials

The cement used was a Canadian General Use (GU) Portland type, equivalent to ASTM Type I. F Class fly ash (FA) and silica fume (SF) were used. Physical and chemical properties of cement, FA, SF and expanded furnace slag (F-Slag) are presented in Table 1. FA and SF were incorporated into the mixture at fixed percentage by mass of total binder at 15 and 5%, respectively.

Table 1. Characteristic of cement, fly ash, silica fume and expanded furnace slag

Chemical	Cement	Fly Ash	Silica fume	F-Slag
SiO_2 (%)	19.60	53.80	95.21	37.1
Al_2O_3 (%)	4.90	21.40	-	8.8
Fe_2O_3 (%)	3.10	5.60	-	1.9
CaO (%)	61.40	3	-	40.0
MgO (%)	3.00	-	-	11.5
SO_3 (%)	3.60	0.5	0.33	-
Alkalis as Na_2O (%)	0.70	0.7	0.85	0.80
LOI (%)	2.30	2.2	1.97	1.99
Physical				
Blaine (cm^2/g)	3870	-	-	-
+ 45 µm (%)	3.00	17	2.85	-
Density (g/cm^3)	3.15	2.48	2.20	-

Nominal size of 4.75 mm and 12 mm lightweight expanded furnace slag were used as a fine and coarse aggregates, respectively. Table 1 presents the chemical properties of lightweight expanded furnace slag and Table 2 presents the grading and physical properties. SF was used to develop a sticky mixture, holding the coarse aggregate in place and preventing aggregates from floating over the surface, hence enhancing the segregation resistance. A polycarboxylate ether type high range water reducer (HRWR) with a specific gravity of 1.05 and total solid content of 26% was used.

Table 2. Grading and physical properties of aggregates

Sieve size (mm)	**% Passing by mass**	
	Fine F -Slag	**Coarse F-Slag**
13.20	-	100.0
9.50	-	90.3
4.75	100	23.2
2.36	81.2	10.2
1.18	46.1	0
0.60	21.5	-
0.30	11.3	-
0.15	6.8	-
Bulk specific gravity (dry)	2.17	1.61
Bulk specific gravity (SSD)	2.20	1.75
Dry loose (kg/m^3)	1075	885
Absorption (%)	6.0	8.0

2.1.2 Mix design methodology and mixture proportion

Eighteen concrete mixtures were designed by following the Box-Wilson central composite design (CCD) method. Three input factors were used in the test program such as X_1 (total binder content), X_2 (percentage of HRWRA as a percentage of mass of cementing materials), and X_3 (water-binder ratio: w/b). The ranges of the input factors were set at 410 to 550 kg/m^3 for X_1, 0.3 to 1.2% for X_2, and 0.30 to 0.40 for X_3. Table 3 presents the coded value and the input factors.

Table 3. Limit and coded value of factors

Factor	**Range**	**Coded Value**				
		-1.414	**-1**	**0**	**+1**	**+1.414**
X1	0.30 to 0.40	0.28	0.30	0.35	0.40	0.42
X2	0.03 to 1.2%	0.11	0.30	0.75	1.2	1.39
X3	410 to 550	380	410	480	550	580

		Factors		
CCD portion	**Mixture**	**X1**	**X2**	**X3**
Fractional factorial	1 to 8	±1	±1	±1
Center point	15 to18	0	0	0
Axial	9 to14	0, ±1.414	0, ±1.414	0, ±1.414

The CCD method consists of three portions: the fraction factorial portion, the center portion and the axial portion. The mix design and statistical evaluation of the test results were performed by means of software called "Design Expert v.8.1" at a 0.05 level of significance. Table 4 presents the mixture propositions for FS-LWSCC developed by the software.

Table 4. Mixture proportions for FS-LWSCC

								Aggregate	
Mix No	**X1** *(w/b)*	**X2** *(HRWRA)*	**X3** *(binder) kg/m^3*	**Cement** *kg/m^3*	**FA** *kg/m^3*	**SF** *kg/m^3*	**Water** *(l/m^3)*	**F-Slag Coarse** *(kg/m^3)*	**F-Slag Fine** *(kg/m^3)*
1	0.40	1.20	550	440	82.5	27.5	220	462	656
2	0.40	1.20	410	328	61.5	20.5	164	550	774
3	0.40	0.30	550	440	82.5	27.5	220	467	659
4	0.40	0.30	410	328	61.5	20.5	164	553	780
5	0.30	1.20	550	440	82.5	27.5	165	509	717
6	0.30	1.20	410	328	61.5	20.5	123	586	824
7	0.30	0.30	550	440	82.5	27.5	165	515	724
8	0.30	0.30	410	328	61.5	20.5	123	585	830
9	0.42	0.75	480	384	72.0	24.0	201	500	705
10	0.28	0.75	480	384	72.0	24.0	134	557	786
11	0.35	1.39	480	384	72.0	24.0	168	527	743
12	0.35	0.11	480	384	72.0	24.0	168	530	750
13	0.35	0.75	580	464	87.0	29.0	203	470	665
14	0.35	0.75	380	304	57.0	19.0	133	585	825
15	0.35	0.75	480	384	72.0	24.0	168	528	747
16	0.35	0.75	480	384	72.0	24.0	168	528	747
17	0.35	0.75	480	384	72.0	24.0	168	528	747
18	0.35	0.75	480	384	72.0	24.0	168	528	747

2.1.3 Casting of test specimens

All concrete mixtures were prepared in 35 L batches in a drum rotating mixer. Due to the high absorption rate of the expanded furnace slag, the lightweight aggregates were pre-soaked for a minimum of 72 hours, then were first mixed for 5 min with 75% of mixing water followed by the addition of cementitious materials and mixing for another 1 min. Finally, the remaining water and HRWR were added to the mixture, and mixed for another 15 min.

Subsequently to mixing of the concrete, slump flow, L-box, V-funnel, J-ring flow, filling capacity, sieve segregation, bleeding, air content, unit weight and setting time tests were conducted. From each batch, ten 100 x 200 mm cylinders were cast for compressive strength determination.

All FS-LWSCC specimens were cast without compaction or mechanical vibration. After casting, all the specimens were covered with plastic sheets and water-saturated burlap and left at room temperature for 24 h. Then, they were demolded and transferred to the moist curing room maintained at 23 ± 2 °C and 100% relative humidity until testing. The cylinders for the oven dry unit weight test were stored in lime-saturated water for 28 days prior to transfer to the oven at 100 °C. The cylinders for the air dry unit weight test were stored in lime-saturated water for 28 days prior to transfer to room temperature.

2.1.4 Testing procedures

All fresh tests were conduct as per EFNARC-Self Compacting Concrete Committee test procedures [3]. The slump flow test was conducted to assess the workability of concrete without obstructions. Flow diameter was the results of slump flow test. The deformability of FS-LWSCC was measured using the V-funnel test, where the flow time under gravity is determined. The filling capacity, J-ring and L-box tests indicate the passing ability of concrete. The sieve segregation resistance (SSR) test was conducted accordingly to EFNARC test procedures, pouring a 5 kg of fresh concrete over 5 mm mesh and the mass of the mortar passing through the sieve was recorded. The air content of FS-LWSCC mixture was determent by using the volumetric method as per ASTM C 173 producer [4]. The initial and final set times of concrete mixtures were measured as per ASTM C 403 procedures [5]. The compressive strength of FS-LWSCC mixtures was determined as per to ASTM C 39 [6] by using 100x200 mm cylinders.

3. RESULTS AND DISCUSSION

The fresh and hardened properties of FS-LWSCC mixtures are summarized in Table 5. Mixes 1, 2, 9 and 11 showed acceptable workability performance, however unbalanced density and noticeable segregation during fresh testing. In contrary, mixes 3, 4, 5, 6, 7, 8, 10, 12 and 13 showed poor workability and passing ability, disqualifying the mixes as SCC. Mixes 14, 15, 16, 17 and 18 met all SCC fresh performance criteria outlined by EFNARC with a balanced density and proper mix proportions. The compressive strength ranged from 18 to 37 and 25 to 49 MPa at 7 and 28-day, respectively. The compressive strength was greatly influenced by the binder content and w/c.

Table 5. Test results on fresh and hardened properties

Mix No.	**Slump Flow (mm)**	**V-funnel (s)**	**J-Ring Flow (mm)**	**J-Ring Height Diff (mm)**	**L-Box ratio**	**Filling capacity (%)**	**Bleeding (ml/cm^2)**	**SSR (%)**	**Air content (%)**	**Set time (h:m)**		**Compressive Strength (MPa)**	
										Initial	**Final**	**7-day**	**28-day**
1	810	2.10	800	0.00	1.00	100	0.057	17	2.7	6:40	9:10	19	27
2	800	1.50	785	0.00	1.00	100	0.072	37	2.5	7:30	10:20	14	21
3	510	2.30	475	3.50	0.52	55	0.043	7	3.2	5:30	7:10	21	30
4	520	7.00	490	4.50	0.50	55	0.053	25	3.4	6:30	8:30	16	24
5	610	14.0	585	2.50	0.72	71	0.008	11	2.8	5:30	7:55	26	38
6	625	15.0	610	3.50	0.59	63	0.010	21	3.0	5:55	8:10	24	35
7	350	24.0	310	16.5	0.30	28	0.004	5	2.6	4:10	6:15	29	41
8	380	20.0	340	10.5	0.38	32	0.006	6	2.4	4:25	6:45	27	38
9	780	1.80	765	0.00	1.00	100	0.038	31	2.2	6:20	8:35	13	20
10	390	26.0	345	10.0	0.28	32	0.000	7	4.8	4:05	6:10	32	44
11	800	4.20	785	0.00	1.00	100	0.031	25	2.6	6:50	9:20	19	31
12	380	8.00	350	12.5	0.32	28	0.010	8	3.8	4:25	6:20	24	37
13	565	8.20	535	4.50	0.68	69	0.006	7	2.8	4:45	6:30	27	40
14	760	2.40	745	0.00	1.00	100	0.108	31	2.2	5:45	8:20	16	24
15	660	4.80	640	2.50	0.89	87	0.011	16	3.2	4:30	6:25	26	39
16	690	4.80	670	1.50	0.95	94	0.021	14	3.4	4:50	6:55	23	34
17	660	5.30	640	2.00	0.91	90	0.012	13	4.0	5:35	7:10	25	37
18	680	4.90	665	1.50	0.93	94	0.019	15	3.8	5:20	7:40	23	35

The fresh unit weight of FS-LWSCC mixtures presented in Table 6 ranged from 1860 to 2020 kg/m^3, classifying the mixtures as semi-lightweight concrete. The 28d air dry values were generally below the 1850 kg/m^3 limit, classifying the FS-LWSCC as lightweight concrete. All 28d oven dry values were well below the 1850 kg/m^3 boundary for lightweight concrete.

The model analysis of the response was carried and the effective test parameters on the mentioned FS-LWSCC were determined. The p –value in Table 7 shows the significance of the given test parameters on the test results. If a system has a p -value $0.05 \leq$ it is accepted as significant factor on the test result.

Table 6. Test results on unit weight properties

Mix No	**Unit weight (kg/m^3)**		
	Fresh	**Air dry**	**Oven dry**
1	1922	1802	1762
2	1950	1815	1756
3	1965	1845	1785
4	1975	1858	1805
5	1985	1865	1805
6	1993	1873	1823
7	2000	1880	1820
8	1870	1720	1672
9	1890	1770	1680
10	1930	1780	1733
11	1940	1798	1740
12	1900	1764	1712
13	2020	1885	1846
14	1860	1740	1710
15	1930	1810	1746
16	1910	1790	1713
17	1900	1780	1720
18	1903	1783	1723

A high correlation coefficient $R^2 > 0.94$ was calculated for the slump flow, V- funnel, J- ring, height, L-box, filling capacity, SSR, Set times. Lower R^2 (0.89 to 0.73) was calculated for 7d, 28d compressive strength, fresh and 28d oven dry unit weight. Where low R^2 (0.55 to 0.58) was calculated for bleeding, air (%), 28d air dry. Table 8 presents the mathematical formulations of LWSCC –Slag Properties and the model statistical evaluation.

4. CONCLUSION

An experimental program using statistically developed mixtures was set up to assess slump flow, L – box, V-funnel, J-ring flow, filling capacity, sieve segregation resistance, bleeding, air content, unit weight, setting time and compressive strength of FS-LWSCC. The following conclusions can be drawn from the study:

1- It is possible to produce robust FS-LWSCC mixtures satisfying the EFNARC criteria for SCC.
2- The slump flow, L – box, V-funnel, J-ring flow and filling capacity test results are influenced by the w/b and SP (%) parameters. While the total binder content does not affect the result greatly.
3- The sieve segregation index value is equally affected by all three parameters, w/b, SP (%) and total binder content.
4- Both initial and final setting times are influenced by all three parameters, w/b, SP (%) and total binder content.
5- The fresh unit weight is influenced only by the binder content; while both 28-d air and oven dry unit weight are affected by w/b.
6- 7-d strength results is affected by all three parameters, on the other hand the 28-d results is only affected by both w/b and total binder content.
7- Air content (%), proven not to be influenced by any of the three investigated parameters.
8- Bleed water is affected by both w/b and total binder content.

9- The derived statistical model and respond table are useful tools to predict the fresh and hardened properties of FS-LWSCC mixture and further optimize the mixtures in simplified - timely fashion.

10- Additional research is needed to validate the applicability of the model to LWSCC with varying gradation and shapes of aggregates.

Table 7. Analysis of GLM- ANOVA model

Dependent variable	***Source of variation***	***Statistical parameters***					***Significant***
		DOF	**Sum of Square**	**Mean square**	**F**	***p*-value**	
Slump Flow	W/B	1	1.254E+005	1.254E+005	51.58	<0.0001	Y
	HRWRA (SP)	1	2.349E+005	2.349E+005	96.66	<0.0001	Y
	Binder	1	8665.92	8665.92	3.57	0.0957	N
V-Funnel	W/B	1	742.99	742.99	178.99	<0.0001	Y
	HRWRA (SP)	1	56.22	56.22	13.54	0.0062	Y
	Binder	1	4.39	4.39	1.06	0.3337	N
J-Ring Flow	W/B	1	1.406E+005	1.406E+005	49.36	0.0001	Y
	HRWRA (SP)	1	2.641E+005	2.641E+005	92.71	< 0.0001	Y
	Binder	1	10431.12	10431.12	3.66	0.0920	N
J-Ring Height	W/B	1	127.68	127.68	69.08	< 0.0001	Y
	HRWRA (SP)	1	181.57	181.57	98.24	< 0.0001	Y
	Binder	1	9.00	9.00	4.87	0.0584	N
L-Box	W/B	1	0.35	0.35	29.52	0.0006	Y
	HRWRA (SP)	1	0.55	0.55	46.53	0.0001	Y
	Binder	1		0.012	1.05	0.3360	N
Filling Capacity	W/B	1	3751.22	3751.22	42.13	0.0002	Y
	HRWRA (SP)	1	5888.51	5888.51	66.14	< 0.0001	Y
	Binder	1	134.33	134.33	1.51	0.2542	N
Sieve Segregation Resistance	W/B	1	493.33	493.33	57.70	< 0.0001	Y
	HRWRA (SP)	1	374.55	374.55	43.80	< 0.0001	Y
	Binder	1	574.14	574.14	67.15	< 0.0001	Y
Bleeding	W/B	1	5.239E-003	5.239E-003	12.22	0.0036	Y
	HRWRA (SP)	1					N
	Binder	1	2.527E-003	2.527E-003	5.89	0.0293	Y
Air Content	W/B	1	0.60	0.60	1.25	0.2966	N
	HRWRA (SP)	1	0.44	0.44	0.92	0.3661	N
	Binder	1	0.061	0.061	0.13	0.7308	N
Set Time Initial	W/B	1	6.96	6.96	52.48	< 0.0001	Y
	HRWRA (SP)	1	5.05	5.05	38.04	0.0003	Y
	Binder	1	1.15	1.15	8.67	0.0186	Y
Set Time Final	W/B	1	7.73	7.73	51.72	< 0.0001	Y
	HRWRA (SP)	1	10.44	10.44	69.84	< 0.0001	Y
	Binder	1	2.85	2.85	19.04	0.0024	Y
7 days compressive strength	W/B	1	329.39	329.39	82.80	< 0.0001	Y
	HRWRA (SP)	1	24.29	24.29	6.10	0.0269	Y
	Binder	1	73.08	73.08	18.37	0.0008	Y
28 days compressive strength	W/B	1	587.18	587.18	65.96	< 0.0001	Y
	HRWRA (SP)	1	34.97	34.97	3.93	0.0675	N
	Binder	1	138.17	138.17	15.52	0.0015	Y
Fresh Unit Weight	W/B	1	714.08	714.08	0.58	0.4680	N
	HRWRA (SP)	1	777.12	777.12	0.63	0.4497	N
	Binder	1	8086.73	8086.73	6.57	0.0334	Y
28- Air Dry Unit	W/B	1	9349.48	9349.48	13.63	0.0024	Y
	HRWRA (SP)	1	317.23	317.23	0.46	0.5075	N
	Binder	1	1668.98	1668.98	2.43	0.1411	N
28 -Oven Dry Unit	W/B	1	12659.70	12659.70	19.58	0.0022	Y
	HRWRA (SP)	1	282.11	282.11	0.44	0.5275	N
	Binder	1	1174.93	1174.93	1.82	0.2146	N

Table 8. Mathematical Formulation of LWSCC –Slag Properties

Response	R^2	**Model Significant**	**Final Equation in Terms of Actual Factors**
Slump Flow	0.96	Y	-2377.92228+13865.62034* W/B+421.31212* HRWRA+0.35406* B+416.66667* W/B * HRWRA+1.60714* W/B* B+0.13889* HRWRA * B-18436.15728* W/B^2-215.26120* HRWRA^2-1.46180E-003* B^2
V-Funnel	0.96	Y	+277.97478-1379.62885* W/B-29.15791* HRWRA+0.027056* B+51.11111* W/B * HRWRA-0.2571* W/B * B+1.58730E-003* HRWRA * B+1867.64401* W/B^2+3.79807* HRWRA^2+7.33009E-005* B^2
J-Ring Flow	0.96	Y	-2682.82605+15217.26699* W/B+449.37711* HRWRA+0.43510* B+416.66667* W/B * HRWRA+1.96429* W/B * B+0.13889* HRWRA * B-20439.53520* W/B^2-221.47574* HRWRA^2-1.71514E-003* B^2
J-Ring Height	0.96	Y	+68.77952-389.80724* W/B-36.99747* HRWRA+0.11265* B+72.22222* W/B * HRWRA-0.21429* W/B * B-0.023810* HRWRA* B+533.22974* W/B^2+9.66950* HRWRA^2-7.76922E-006* B^2
L-Box	0.94	Y	-8.37403+40.21813* W/B+0.35834* HRWRA+6.04977E-003* B+1.94444* W/B * HRWRA-1.07143E-003* W/B * B+7.53968E-004* HRWRA * B-53.92636* W/B^2-0.61637* HRWRA^2-6.97710E-006* B^2
Filling Capacity	0.95	Y	-799.71274+3767.67435* W/B+92.93445* HRWRA+0.53155* B+88.88889* W/B * HRWRA-0.14286* W/B * B+0.047619* HRWRA * B-4874.51245* W/B^2-65.11744* HRWRA^2-5.88434E-004* B^2
Sieve Segregation	0.94	Y	-166.73490+586.92569* W/B+31.42305* HRWRA+0.27176* B+5.55556* W/B* HRWRA-0.96429* W/B * B-0.043651* HRWRA * B
Bleeding	0.58	Y	-0.028644+0.41790* W/B+0.013092* HRWRA-2.06588E-004* B
Air Content	0.58	Y	-26.11008+17.38976* W/B+5.29908* HRWRA+0.10572* B-12.22222* W/B * HRWRA+9.58878E-016* W/B * B-1.55763E-017* HRWRA * B-18.12097* W/B^2-0.96446* HRWRA^2-1.09073E-004* B^2
Set Time Initial	0.94	Y	+9.68059-21.81549* W/B-0.41156* HRWRA-0.012817* B-2.22222* W/B * HRWRA-0.053571* W/B * B-1.62772E-017* HRWRA * B+92.04387* W/B^2+1.75363* HRWRA^2+2.82901E-005* B^2
Set time Final	0.96	Y	+22.52935-37.23357* W/B-3.02722* HRWRA-0.041747* B+4.72222* W/B * HRWRA-0.051786* W/B * B-5.95238E-004* HRWRA * B+106.57479* W/B^2+2.48858* HRWRA^2+5.56090E-005* B^2
7d- Strength	0.89	Y	+49.62476-104.78343* W/B-3.16131* HRWRA+0.035135* B
28d Strength	0.86	Y	+66.67720-139.90188* W/B-3.79357* HRWRA+0.048311* B
Fresh Unit Weight	0.73	Y	+1915.62297+780.53723*W/B+552.97903* HRWRA-1.76442*B-977.77778*W/B*HRWRA-5.71429*W/B* B-0.61905* HRWRA* B+3630.53191* W/B^2+69.51274* HRWRA^2+4.78989E-003* B^2
28 Air dry Unit	0.55	Y	+1967.47519-558.25553* W/B-11.42565* HRWRA+0.16791* B
28 Oven Dry Unit	0.81	Y	+1811.51834+2269.72598* W/B-75.09324* HRWRA-1.36050* B-200.00000* W/B * HRWRA-1.14286* W/B * B-0.10317* HRWRA * B-3172.51723* W/B^2+122.56152*

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