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SPREADSHEET APPLICATIONS IN BUILDING MATERIAL RESEARCH STUDIES

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ABSTRACT

Spreadsheets are widely used computer software due to their simplicity and user friendliness. They are available on most of the computers and mainly used for data management, calculation, making charts or statistical analysis. However, their potential in materials research is not fully explored yet. In this paper various applications of spreadsheets in different building material research studies have been presented. Their use particularly in computation of the engineering material properties like strength, modulus, thermal conductivity, heat of hydration; mix design; numerical differentiation & integration; and statistical analysis are described with case studies using Microsoft Excel™. The advantages and limitations of the spreadsheets in such applications are also discussed.

INTRODUCTION

A spreadsheet is a computer programme that has several built-in statistical and graphics functions. Microsoft Office Excel is the most commonly used spreadsheet software programme. Lotus 1-2-3, Quattro Pro and Open Office Calc are some other popular spreadsheet programmes. In spreadsheets entering data in the form of numbers or text, and formulae is a quick and simple task. Further they facilitate importing and exporting data, easy calculation, data analysis and graphical presentation with various formats. The capability of the spreadsheets can be further enhanced by various 'add-in' software easily available on the internet as free or commercial products. In addition, numerous worksheet functions can be written as 'macros' that allow combination of different commands. The macros can be either written in a computer language called Visual Basic for Applications (VBA) or recorded. They can be run whenever similar tasks

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have to be executed. This is a very valuable facility for running repetitive tasks. The other feature is that the spreadsheets containing various data can be interlinked.

The use of paper-based spreadsheets is an old practice. They have been used for hundreds of years for keeping records and accounting purposes. However, the use of computer based spreadsheet began from 1979 when Dan Bricklin conceptualise it and Bob Frankston wrote the programme on Apple II platform [1]. Initially, the PC based spreadsheets were written for accounting applications, but with time their use gradually increased in different fields. Nowadays spreadsheets are widely used in laboratory experiments for collecting, storing and analysis of data.

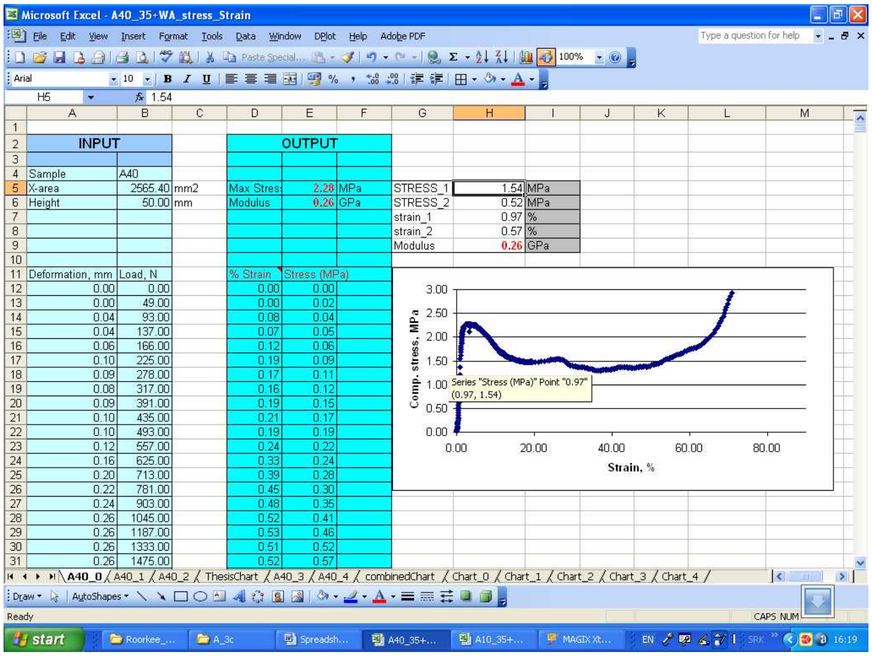
The main reason behind the wider use of spreadsheets is that it is easier and quicker to use a spreadsheet than write a computer program. A person using spreadsheet is not essential to be a computer programmer. Moreover, if some modification is required it is difficult to understand the underneath mathematics in other programmes, while spreadsheets are more convenient. What-If Analysis and Solver are very useful features in Excel spreadsheet. In What-If Analysis the change in output can be assessed for a given change in inputs, while Solver, an add-in for Excel spreadsheet, is very helpful to optimize models with multiple variables and constraints. For example, in concrete mix design the strength is to be optimised by varying the contents of cement, aggregates, water and pozzolanic materials like fly ash and silica fume. However, to control the cost and to meet the durability and workability requirements the use of cement and water should be within certain limits. These limits have to be the constraints in the concrete optimising models.

Around the world different types of alternative building materials are being developed, particularly there is a big boom in composites and repair materials. These materials have to be tested and evaluated for different properties before their use [2-4]. In building materials research the test data are obtained from various sources such lab experimentation, test machines and data acquisition systems, mainly in the ASCII format, which need to be analysed and presented. This paper illustrates the use of spreadsheets in solving a variety of problems in building materials research activities.

MECHANICAL PROPERTIES

To asses the behaviour of materials under loads various mechanical properties like strength (tensile, compression and flexural), Young’s modulus and Poisson’s ratio are determined. Most of these properties can be evaluated by plotting load-deformation or stress-strain curves under respective loading configurations. For each test specimen load versus deformation data are generally recorded using either a computerised test machine or by an automatic data logger. The data are then transferred to a spreadsheet. After calculations using this data set the specimen size data a stress-strain curve is obtained for each specimen. For several similar test specimens this becomes a repetitive task. For this purpose a macro can be written or a spreadsheet can be designed. An example is shown in Fig. 1, where the inputs is the load-deformation data and specimen size and output are maximum or ultimate strength and modulus values.

Now-a-days most of the test machines are equipped with computer software which can plot stress-stain curves, but spreadsheets are still useful for combining various curves and presentation of the curves in the desired formats.



	A	B	C	D	E	F	G	H	I
1									
2	INPUT			OUTPUT					
3									
4	Sample	A40							
5	X-area	2565.40	mm2	Max Stres	2.28	MPa	STRESS_1	1.54	MPa
6	Height	50.00	mm	Modulus	0.26	GPa	STRESS_2	0.52	MPa
7							strain_1	0.97	%
8							strain_2	0.57	%
9							Modulus	0.26	GPa
10									
11	Deformation, mm	Load, N		% Strain	Stress (MPa)				
12	0.00	0.00		0.00	0.00				
13	0.00	49.00		0.00	0.02				
14	0.04	93.00		0.08	0.04				
15	0.04	137.00		0.07	0.05				
16	0.06	166.00		0.12	0.06				
17	0.10	225.00		0.19	0.09				
18	0.09	278.00		0.17	0.11				
19	0.08	317.00		0.16	0.12				
20	0.09	391.00		0.19	0.15				
21	0.10	435.00		0.21	0.17				
22	0.10	493.00		0.19	0.19				
23	0.12	557.00		0.24	0.22				
24	0.16	625.00		0.33	0.24				
25	0.20	713.00		0.39	0.28				
26	0.22	781.00		0.45	0.30				
27	0.24	903.00		0.48	0.35				
28	0.26	1045.00		0.52	0.41				
29	0.26	1187.00		0.53	0.46				
30	0.26	1333.00		0.51	0.52				
31	0.26	1475.00		0.52	0.57				

Figure 1 A spreadsheet used for plotting stress-stain curve using data from test machine.

ENERGY ABSORPTION EFFICIENCY

Cellular materials, like foams undergo a large deformation before complete crushing. This property of these materials is exploited for several energy absorption applications, like helmets, crash barriers, motor vehicles and aerospace structures. The energy absorption up to any strain (ε) can be obtained by integrating the area under the stress-strain curve up to that strain. There are various methods adopted for evaluating characteristics and selection of a suitable energy absorbing material for a given application. These methods include: (i) energy absorption capacity (ii) energy absorption efficiency and (iii) energy absorption diagram. '*Energy absorption efficiency* (η)' is a convenient parameter. It can be defined as the percentage ratio of energy absorbed by a real material to that of an ideal energy absorber at a given strain (ε) and can be expressed as following [5]:

$$\eta = \frac{\int_0^{\varepsilon} \sigma . d\varepsilon}{\sigma_{\max} . \varepsilon} \times 100 \tag{1}$$

where $\sigma_{\max}$ is the maximum stress recorded up to the strain ε. Thus, an ideal energy absorber shows a rectangular stress-strain curve until maximum permissible deformation, while brittle materials have negligible area after the peak. A typical curve showing change in energy absorption efficiency is presented in Fig.2 and the spreadsheet computations of various parameters are shown in Fig 3. In this spreadsheet the inputs are same as they were for the spreadsheet used for stress-strain curve shown in Fig. 1.

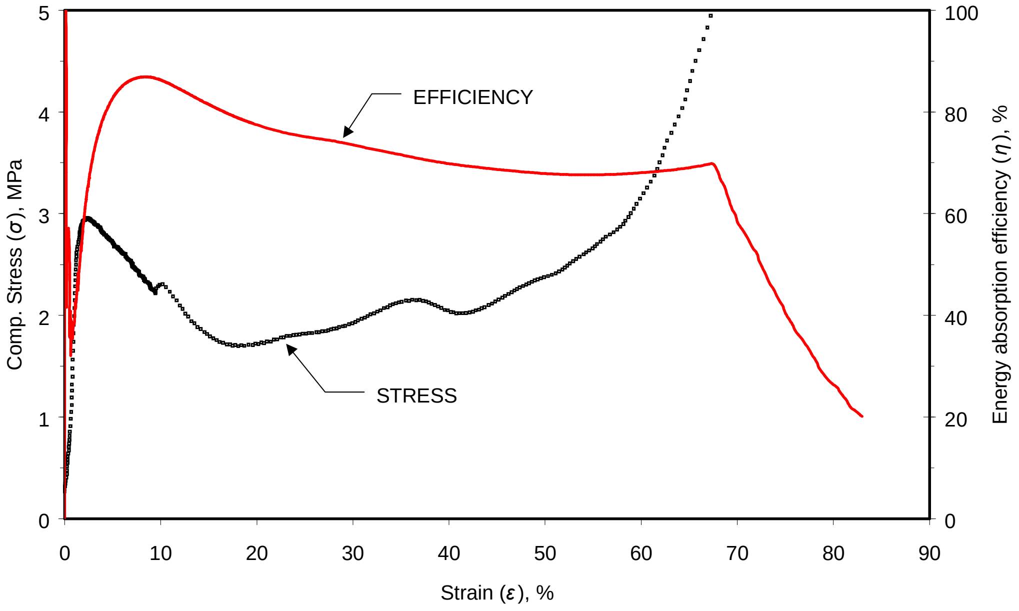
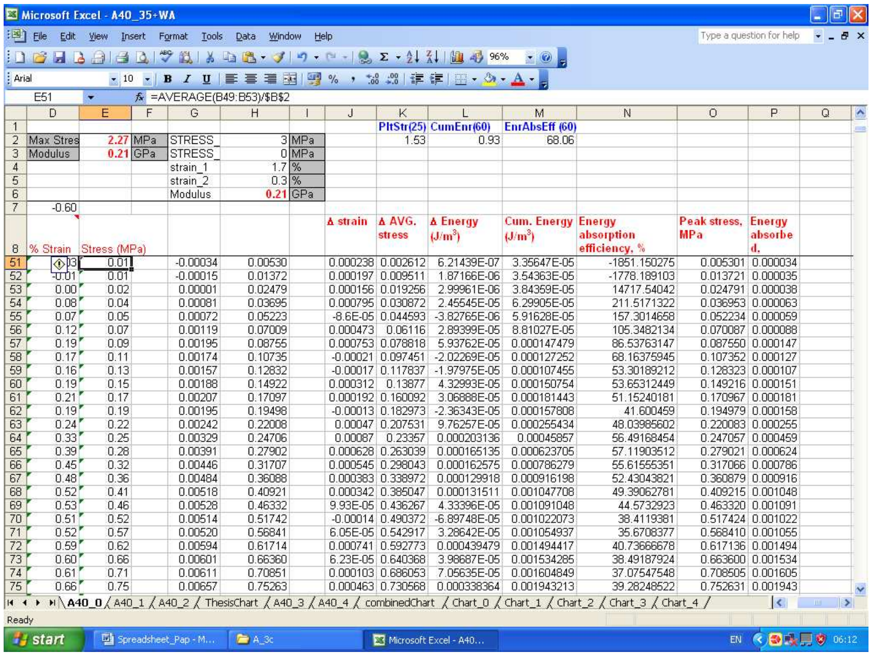


Figure 2 Compressive stress-strain curve and energy absorption efficiency.



Microsoft Excel - A40_35+WA

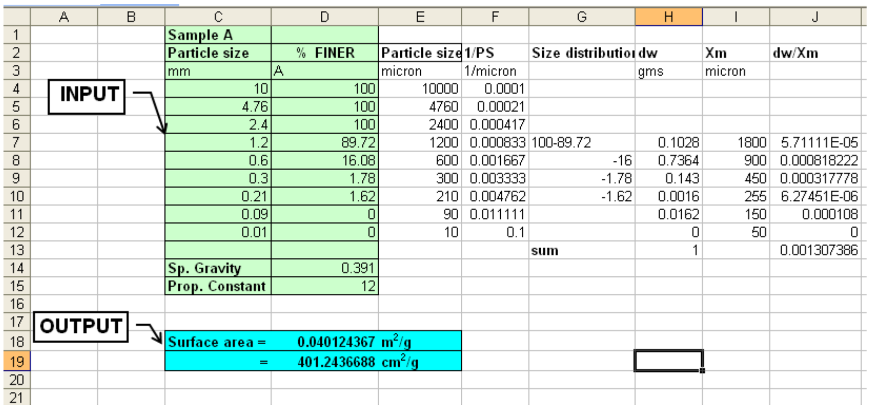
E51 =AVERAGE(B49:B53)/$B$2

	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1								PltStr(25)	CumEnr(60)	EnrAbsEff (60)				
2	Max Stres	2.27	MPa	STRESS_	3	MPa		1.53	0.93	68.06				
3	Modulus	0.21	GPa	STRESS_	0	MPa								
4				strain_1	1.7	%								
5				strain_2	0.3	%								
6				Modulus	0.21	GPa								
7	-0.60													
8	% Strain	Stress (MPa)					Δ strain	Δ AVG. stress	Δ Energy (J/m^3)	Cum. Energy (J/m^3)	Energy absorption efficiency, %	Peak stress, MPa	Energy absorbed.	
51	03	0.01		-0.00034	0.00530		0.000238	0.002612	6.21439E-07	3.35647E-05	-1851.150275	0.005301	0.000034	
52	-0.01	0.01		-0.00015	0.01372		0.000197	0.009511	1.87166E-06	3.54363E-05	-1778.189103	0.013721	0.000035	
53	0.00	0.02		0.00001	0.02479		0.000156	0.019256	2.99961E-06	3.84359E-05	14717.54042	0.024791	0.000038	
54	0.08	0.04		0.00081	0.03695		0.000795	0.030872	2.45545E-05	6.29905E-05	211.5171322	0.036953	0.000063	
55	0.07	0.05		0.00072	0.05223		-8.6E-05	0.044593	-3.82765E-06	5.91628E-05	157.3014658	0.052234	0.000059	
56	0.12	0.07		0.00119	0.07009		0.000473	0.06116	2.89399E-05	8.81027E-05	105.3482134	0.070087	0.000088	
57	0.19	0.09		0.00195	0.08755		0.000753	0.078818	5.93762E-05	0.000147479	86.53763147	0.087550	0.000147	
58	0.17	0.11		0.00174	0.10735		-0.00021	0.097451	-2.02269E-05	0.000127252	68.16375945	0.107352	0.000127	
59	0.16	0.13		0.00157	0.12832		-0.00017	0.117837	-1.97975E-05	0.000107455	53.30189212	0.128323	0.000107	
60	0.19	0.15		0.00188	0.14922		0.000312	0.13877	4.32993E-05	0.000150754	53.65312449	0.149216	0.000151	
61	0.21	0.17		0.00207	0.17097		0.000192	0.160092	3.06888E-05	0.000181443	51.15240181	0.170967	0.000181	
62	0.19	0.19		0.00195	0.19498		-0.00013	0.182973	-2.36343E-05	0.000157808	41.600459	0.194979	0.000158	
63	0.24	0.22		0.00242	0.22008		0.00047	0.207531	9.76257E-05	0.000255434	48.03985602	0.220083	0.000255	
64	0.33	0.25		0.00329	0.24706		0.00087	0.23357	0.000203136	0.00045857	56.49168454	0.247057	0.000459	
65	0.39	0.28		0.00391	0.27902		0.000628	0.263039	0.000165135	0.000623705	57.11903512	0.279021	0.000624	
66	0.45	0.32		0.00446	0.31707		0.000545	0.298043	0.000162575	0.000786279	55.61555351	0.317066	0.000786	
67	0.48	0.36		0.00484	0.36088		0.000383	0.338972	0.000129918	0.000916198	52.43043821	0.360879	0.000916	
68	0.52	0.41		0.00518	0.40921		0.000342	0.385047	0.000131511	0.001047708	49.39062781	0.409215	0.001048	
69	0.53	0.46		0.00528	0.46332		9.93E-05	0.436267	4.33396E-05	0.001091048	44.5732923	0.463320	0.001091	
70	0.51	0.52		0.00514	0.51742		-0.00014	0.490372	-6.89748E-05	0.001022073	38.4119381	0.517424	0.001022	
71	0.52	0.57		0.00520	0.56841		6.05E-05	0.542917	3.28642E-05	0.001054937	35.6708377	0.568410	0.001055	
72	0.59	0.62		0.00594	0.61714		0.000741	0.592773	0.000439479	0.001494417	40.73666678	0.617136	0.001494	
73	0.60	0.66		0.00601	0.66360		6.23E-05	0.640368	3.98687E-05	0.001534285	38.49187924	0.663600	0.001534	
74	0.61	0.71		0.00611	0.70851		0.000103	0.686053	7.05635E-05	0.001604849	37.07547548	0.708505	0.001605	
75	0.66	0.75		0.00657	0.75263		0.000463	0.730568	0.000338364	0.001943213	39.28248522	0.752631	0.001943	

Figure 3 Spreadsheet computation of energy absorption efficiency.

SPECIFIC SURFACE AREA OF PARTICLES

In making concrete and composites various aggregate and particulate materials like fly ash, red mud, calcium carbonate and talc powder are used. Their specific surface area is one of the important characteristics that determine the binder requirement, the bond between the particles and the binding matrix and for various other reasons [6]. Fig. 4 shows a spreadsheet programme to determine the surface area of particulate materials using Gates Diagram method. As can be seen the inputs are sieve analysis data, specific gravity or the particle density and a constant of proportionality. The value of the constant of proportionality depends upon the geometrical features of the particles. For blocky irregular shapes the value is 12.



	A	B	C	D	E	F	G	H	I	J
1			**Sample A**							
2			**Particle size**	**% FINER**	**Particle size**	**1/PS**	**Size distributio**	**dw**	**Xm**	**dw/Xm**
3			mm	A	micron	1/micron		gms	micron	
4	**INPUT**		10	100	10000	0.0001				
5			4.76	100	4760	0.00021				
6			2.4	100	2400	0.000417				
7			1.2	89.72	1200	0.000833	100-89.72	0.1028	1800	5.71111E-05
8			0.6	16.08	600	0.001667	-16	0.7364	900	0.000818222
9			0.3	1.78	300	0.003333	-1.78	0.143	450	0.000317778
10			0.21	1.62	210	0.004762	-1.62	0.0016	255	6.27451E-06
11			0.09	0	90	0.011111		0.0162	150	0.000108
12			0.01	0	10	0.1		0	50	0
13							**sum**	1		0.001307386
14			**Sp. Gravity**	0.391						
15			**Prop. Constant**	12						
16										
17	**OUTPUT**									
18			**Surface area =**	**0.040124367 m^2/g**						
19			**=**	**401.2436688 cm^2/g**						
20										
21										

Figure 4 Spreadsheet for determining surface area of particulate materials.

MIX DESIGN

Concrete has been an integral part of the buildings since the beginning of the 20th century. Its properties depend upon the proportion and quality of the constituent materials. The critical factors are the cementitious material and water content. In cementitious materials, besides Portland cement, pozzolanic materials like silica fume, fly ash, slag and metakaolin are also added to improve performance and durability of concrete. The value of water-cement (w/c) ratio is kept as low as possible to achieve high strength and durability. Use of spreadsheets for optimisation of concrete mixes has been presented by Kasperkiewicz [7] and a method of design of trial mixes to determine the quantities of different ingredients using formulae without the use of any charts or tables has been described by Ganju [8].

In concrete mix designs and in use of powders in making composites, the role of particle packing is crucial. This can be achieved by proper selection of aggregates/particles type and particle size distribution. The optimum composition of an aggregate mix can be determined either by using “ideal” grading curves or by means of theoretical and practical determination of aggregate packing value [9]. There are different types of “ideal” curves available such as Bolomey's, Fuller's, Graf's, Rissel's curves, which were obtained by practical experiments and theoretical calculations.

Spreadsheet calculations were used for obtaining an optimal mix of the three different size cork granules of particle size distribution curves shown in Fig 5 [10]. On the same chart a Fuller’s curve for an ideal grading obtained by the following equation was drawn.

$$X_i = \sqrt{\frac{d_i}{d_{\max}}} \tag{2}$$

where X_i is the ideal percentage finer or passing, d_i is particle size and d_{max} is the largest particle size. In the present research d_{max} was 4.76 mm. The optimum mix was determined as large size

(49.6 %), medium size (28.9%) and small size (21.5%). The real mix using this composition is also shown in Fig. 5, which is quite close to the Fuller's curve.

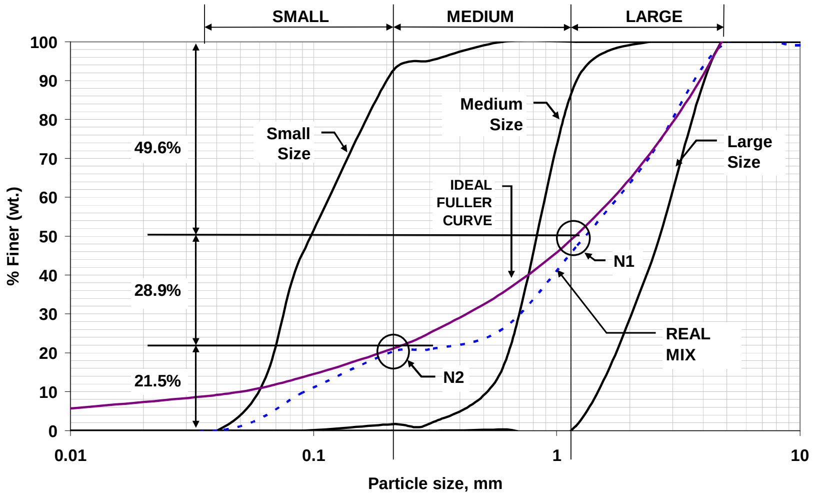


Figure 5 Optimisation of particle grading using Fullers curve.

HEAT OF HYDRATION

Cement is an important building material. When it is mixed with water heat is librated, which indicates setting of cement. Measurement of the heat evolution is useful to understand hydration behaviour of cement, its raw material formulation and its interaction with other ingredients in concrete like materials. In semi-adiabatic technique the hydration tests can be performed in Dewar flasks, where the hydration temperature of each cement-water mix is recorded with the aid of thermocouples connected to a multipoint data recorder. Each sample for the hydration test is prepared by thoroughly mixing cement and admixture, if any, in a plastic bag. The required amount of water is then added and mixed for 2 minutes. A thermocouple is attached to the bag for measuring the temperature change of the mix. The plastic bag is then placed in a Dewar flask for a certain period generally 24 hours. For each replication, a different flask is used so that any possible experimental error could be minimised. All the hydration experiments are carried out in a temperature controlled room. Further details can be seen in [11].

A considerable amount of calculations are required for determination of rate of heat evolution and total heat evolution. For this purpose both numerical differentiation and integration are required. Further details of the calculations can be seen elsewhere [11]. In heat of hydration determination the other important parameters are the values of maximum temperature and maximum heat evolution rate and their corresponding time. For this purpose there is no need to manually check the values. A built in function in Excel spreadsheet can be used as shown in Fig. 7.

For maximum value the Excel spreadsheet function is:

```
= MAX(B3:B95)
```

and for the corresponding value of time in column A is:

```
=INDEX($A$3:$A$95,MATCH(MAX(B3:B95),B3:B95,0))
```

The rate of heat evolution (Q_i), at any instance t_i, was calculated from the following relationship:

$$Q_i = \frac{dH_i}{dt_i} = \left(C_c + C_f\right)\left(\frac{d\left(T_i - T_r\right)}{dt_i} + k\left(T_i - T_r\right)\right) \tag{3}$$

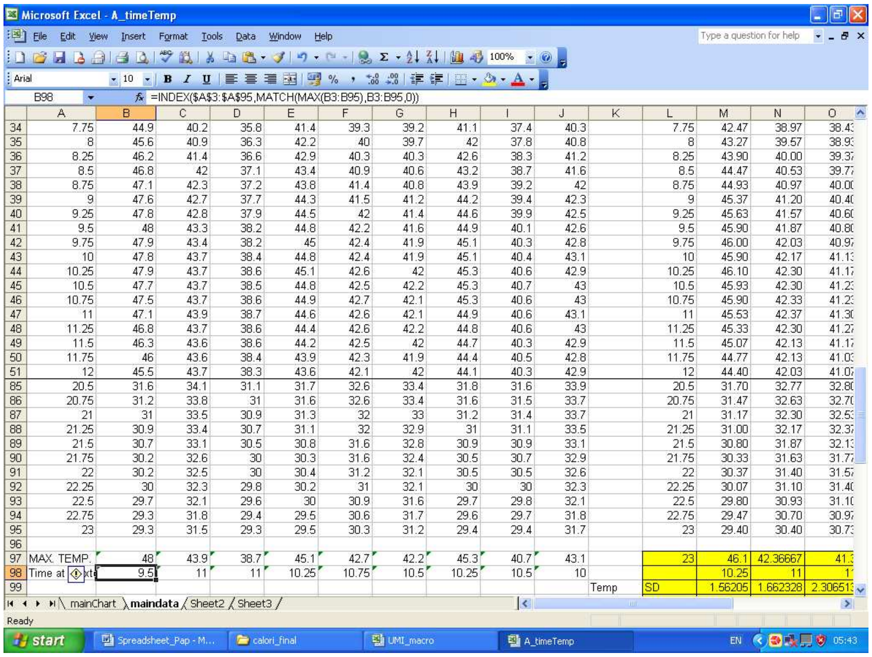
where C_c is the heat capacity of the contents, C_f is the heat capacity of the Dewar flask and k is cooling rate constant. The total heat evolved up to any instance t_i was obtained by integrating the rate of heat evolution with respect to time:

$$H_i = \left(C_c + C_f\right)\left(\left(T_i - T_r\right) + \sum_{0}^{i} k\left(T_i - T_r\right)dt\right) \tag{4}$$

Spreadsheets were also used to obtain the values for the heat of hydration using a maturity function by numerically differentiating the total heat with respect to both, the real time and the '*equivalent time*', calculated using equation (5) at a reference temperature generally 20 ºC. The value of t_{emax} is obtained from the rate of heat evolution curve based on '*equivalent time*' determined using a maturity function proposed by Freiesleben Hansen and Pedersen [12] to compute the equivalent age of concrete, which was based on the Arrhenius equation. This maturity function can be applied to determine the 'equivalent age' (t_e) of various hydration samples that undergo different temperature histories. The following relationship gives the 'equivalent age' at any instance *i*.

$$t_e = \sum_{0}^{i} e^{\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{T'}\right)} dt \tag{5}$$

Where 'E_a' is the apparent activation energy of cement (J/mol), R is the gas constant (8.314 J/mol-K), T and T' are absolute specimen and reference temperatures (Kelvin), respectively.



=INDEX($A$3:$A$95,MATCH(MAX(B3:B95),B3:B95,0))

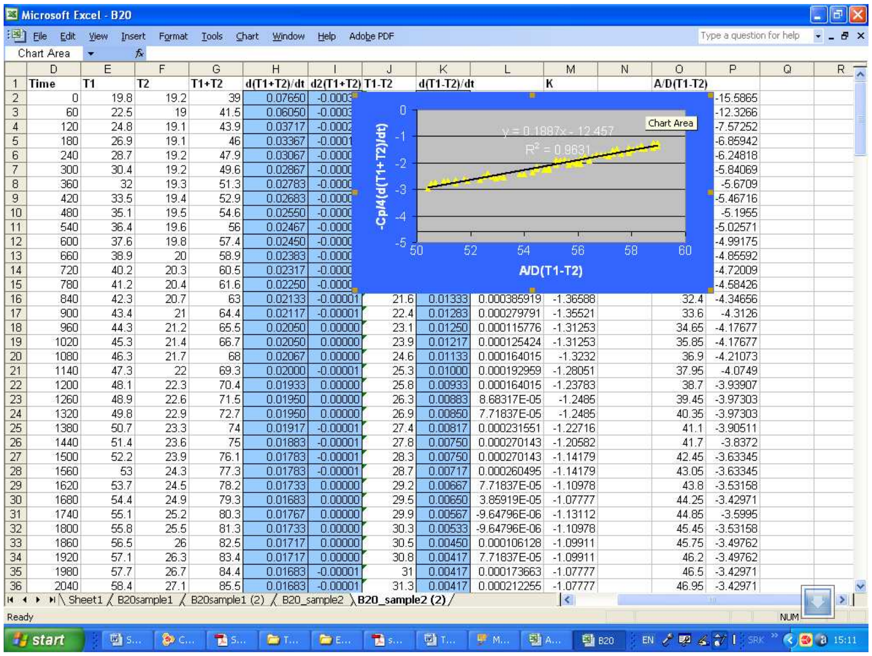
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
34	7.75	44.9	40.2	35.8	41.4	39.3	39.2	41.1	37.4	40.3		7.75	42.47	38.97	38.4
35	8	45.6	40.9	36.3	42.2	40	39.7	42	37.8	40.8		8	43.27	39.57	38.9
36	8.25	46.2	41.4	36.6	42.9	40.3	40.3	42.6	38.3	41.2		8.25	43.90	40.00	39.3
37	8.5	46.8	42	37.1	43.4	40.9	40.6	43.2	38.7	41.6		8.5	44.47	40.53	39.7
38	8.75	47.1	42.3	37.2	43.8	41.4	40.8	43.9	39.2	42		8.75	44.93	40.97	40.0
39	9	47.6	42.7	37.7	44.3	41.5	41.2	44.2	39.4	42.3		9	45.37	41.20	40.4
40	9.25	47.8	42.8	37.9	44.5	42	41.4	44.6	39.9	42.5		9.25	45.63	41.57	40.6
41	9.5	48	43.3	38.2	44.8	42.2	41.6	44.9	40.1	42.6		9.5	45.90	41.87	40.8
42	9.75	47.9	43.4	38.2	45	42.4	41.9	45.1	40.3	42.8		9.75	46.00	42.03	40.9
43	10	47.8	43.7	38.4	44.8	42.4	41.9	45.1	40.4	43.1		10	45.90	42.17	41.1
44	10.25	47.9	43.7	38.6	45.1	42.6	42	45.3	40.6	42.9		10.25	46.10	42.30	41.1
45	10.5	47.7	43.7	38.5	44.8	42.5	42.2	45.3	40.7	43		10.5	45.93	42.30	41.2
46	10.75	47.5	43.7	38.6	44.9	42.7	42.1	45.3	40.6	43		10.75	45.90	42.33	41.2
47	11	47.1	43.9	38.7	44.6	42.6	42.1	44.9	40.6	43.1		11	45.53	42.37	41.3
48	11.25	46.8	43.7	38.6	44.4	42.6	42.2	44.8	40.6	43		11.25	45.33	42.30	41.2
49	11.5	46.3	43.6	38.6	44.2	42.5	42	44.7	40.3	42.9		11.5	45.07	42.13	41.1
50	11.75	46	43.6	38.4	43.9	42.3	41.9	44.4	40.5	42.8		11.75	44.77	42.13	41.0
51	12	45.5	43.7	38.3	43.6	42.1	42	44.1	40.3	42.9		12	44.40	42.03	41.0
85	20.5	31.6	34.1	31.1	31.7	32.6	33.4	31.8	31.6	33.9		20.5	31.70	32.77	32.8
86	20.75	31.2	33.8	31	31.6	32.6	33.4	31.6	31.5	33.7		20.75	31.47	32.63	32.7
87	21	31	33.5	30.9	31.3	32	33	31.2	31.4	33.7		21	31.17	32.30	32.5
88	21.25	30.9	33.4	30.7	31.1	32	32.9	31	31.1	33.5		21.25	31.00	32.17	32.3
89	21.5	30.7	33.1	30.5	30.8	31.6	32.8	30.9	30.9	33.1		21.5	30.80	31.87	32.1
90	21.75	30.2	32.6	30	30.3	31.6	32.4	30.5	30.7	32.9		21.75	30.33	31.63	31.7
91	22	30.2	32.5	30	30.4	31.2	32.1	30.5	30.5	32.6		22	30.37	31.40	31.5
92	22.25	30	32.3	29.8	30.2	31	32.1	30	30	32.3		22.25	30.07	31.10	31.4
93	22.5	29.7	32.1	29.6	30	30.9	31.6	29.7	29.8	32.1		22.5	29.80	30.93	31.1
94	22.75	29.3	31.8	29.4	29.5	30.6	31.7	29.6	29.7	31.8		22.75	29.47	30.70	30.9
95	23	29.3	31.5	29.3	29.5	30.3	31.2	29.4	29.4	31.7		23	29.40	30.40	30.7
96															
97	MAX. TEMP.	48	43.9	38.7	45.1	42.7	42.2	45.3	40.7	43.1		23	46.1	42.36667	41.
98	Time at xt	9.5	11	11	10.25	10.75	10.5	10.25	10.5	10			10.25	11	1
99											Temp	SD	1.56205	1.662328	2.30651

Figure 6 Spreadsheet for evaluating heat of hydration parameters.

THERMAL CONDUCTIVITY MEASUREMENT

Thermal conductivity (λ) is a measure of the ability of a material to conduct heat through it. A low value of λ is desirable for a material like lightweight concrete when it is used for thermal insulation purposes. Several foams and mineral wools are also used for thermal insulation purposes. A material having a low value of λ can provide the same thermal insulation with a thinner wall than a material having a high value of λ. Thus, thermal conductivity has both structural and economic effects on building designs.

The arrangement of a test set-up for a dynamic method of thermal conductivity measurement is discussed in [10]. In this method the test specimen is sandwiched between two thin aluminium plates. The lower plate is heated from the bottom by a hot plate and the upper plate was allowed to cool from the top in a room with a controlled temperature. This assembly is insulated on the sides and bottom by a low-density polystyrene foam to allow one dimensional heat flow through the specimen. The temperatures at the inner surface (T_1) and outer surface of the specimen (T_2) are recorded at small intervals with the help of thermocouples and a data recorder.



	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Time	T1	T2	T1+T2	d(T1+T2)/dt	d2(T1+T2)	T1-T2	d(T1-T2)/dt		K		A/D(T1-T2)			
2	0	19.8	19.2	39	0.07650	-0.0003							-15.5865		
3	60	22.5	19	41.5	0.06050	-0.0003							-12.3266		
4	120	24.8	19.1	43.9	0.03717	-0.0002							-7.57252		
5	180	26.9	19.1	46	0.03367	-0.0001							-6.85942		
6	240	28.7	19.2	47.9	0.03067	-0.0000							-6.24818		
7	300	30.4	19.2	49.6	0.02867	-0.0000							-5.84069		
8	360	32	19.3	51.3	0.02783	-0.0000							-5.6709		
9	420	33.5	19.4	52.9	0.02683	-0.0000							-5.46716		
10	480	35.1	19.5	54.6	0.02550	-0.0000							-5.1955		
11	540	36.4	19.6	56	0.02467	-0.0000							-5.02571		
12	600	37.6	19.8	57.4	0.02450	-0.0000							-4.99175		
13	660	38.9	20	58.9	0.02383	-0.0000							-4.85592		
14	720	40.2	20.3	60.5	0.02317	-0.0000							-4.72009		
15	780	41.2	20.4	61.6	0.02250	-0.0000							-4.58426		
16	840	42.3	20.7	63	0.02133	-0.00001	21.6	0.01333	0.000385919	-1.36588		32.4	-4.34656		
17	900	43.4	21	64.4	0.02117	-0.00001	22.4	0.01283	0.000279791	-1.35521		33.6	-4.3126		
18	960	44.3	21.2	65.5	0.02050	0.00000	23.1	0.01250	0.000115776	-1.31253		34.65	-4.17677		
19	1020	45.3	21.4	66.7	0.02050	0.00000	23.9	0.01217	0.000125424	-1.31253		35.85	-4.17677		
20	1080	46.3	21.7	68	0.02067	0.00000	24.6	0.01133	0.000164015	-1.3232		36.9	-4.21073		
21	1140	47.3	22	69.3	0.02000	-0.00001	25.3	0.01000	0.000192959	-1.28051		37.95	-4.0749		
22	1200	48.1	22.3	70.4	0.01933	0.00000	25.8	0.00933	0.000164015	-1.23783		38.7	-3.93907		
23	1260	48.9	22.6	71.5	0.01950	0.00000	26.3	0.00883	8.68317E-05	-1.2485		39.45	-3.97303		
24	1320	49.8	22.9	72.7	0.01950	0.00000	26.9	0.00850	7.71837E-05	-1.2485		40.35	-3.97303		
25	1380	50.7	23.3	74	0.01917	-0.00001	27.4	0.00817	0.000231551	-1.22716		41.1	-3.90511		
26	1440	51.4	23.6	75	0.01883	-0.00001	27.8	0.00750	0.000270143	-1.20582		41.7	-3.8372		
27	1500	52.2	23.9	76.1	0.01783	-0.00001	28.3	0.00750	0.000270143	-1.14179		42.45	-3.63345		
28	1560	53	24.3	77.3	0.01783	-0.00001	28.7	0.00717	0.000260495	-1.14179		43.05	-3.63345		
29	1620	53.7	24.5	78.2	0.01733	0.00000	29.2	0.00667	7.71837E-05	-1.10978		43.8	-3.53158		
30	1680	54.4	24.9	79.3	0.01683	0.00000	29.5	0.00650	3.85919E-05	-1.07777		44.25	-3.42971		
31	1740	55.1	25.2	80.3	0.01767	0.00000	29.9	0.00567	-9.64796E-06	-1.13112		44.85	-3.5995		
32	1800	55.8	25.5	81.3	0.01733	0.00000	30.3	0.00533	-9.64796E-06	-1.10978		45.45	-3.53158		
33	1860	56.5	26	82.5	0.01717	0.00000	30.5	0.00450	0.000106128	-1.09911		45.75	-3.49762		
34	1920	57.1	26.3	83.4	0.01717	0.00000	30.8	0.00417	7.71837E-05	-1.09911		46.2	-3.49762		
35	1980	57.7	26.7	84.4	0.01683	-0.00001	31	0.00417	0.000173663	-1.07777		46.5	-3.42971		
36	2040	58.4	27.1	85.5	0.01683	-0.00001	31.3	0.00417	0.000212255	-1.07777		46.95	-3.42971		

Figure 7 Spreadsheet for determination of thermal conductivity.

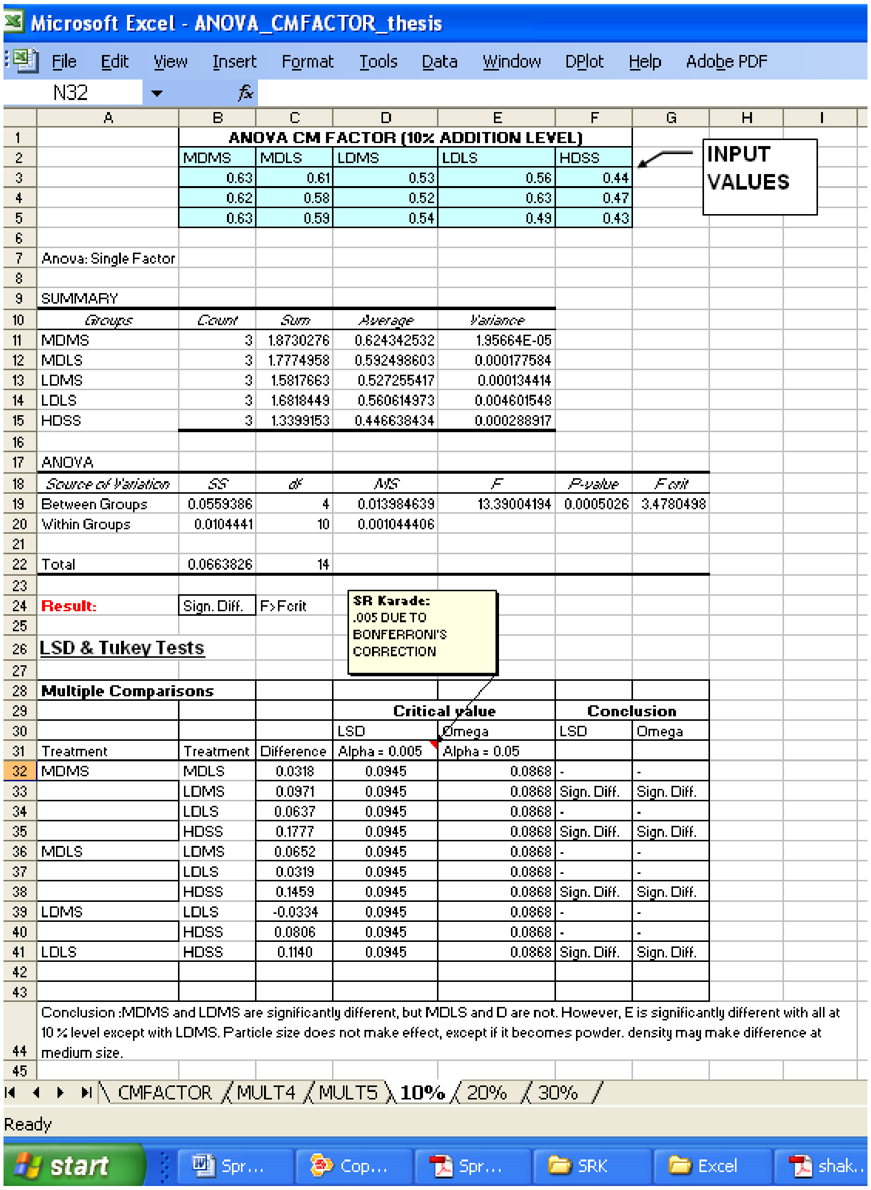
If at any instance (t_i), the rate of heat supplied to the sample is Q_1, the rate of heat going out of the sample is Q_2 and the rate of heat retention within the sample is Q_3. Then the relationship can be expressed as:

$$\frac{\lambda A(T_1 - T_2)}{D} - Q_1 = -\frac{C_p}{4}\frac{d\left(T_1 + T_2\right)}{dt} \qquad (6)$$

where, C_p be the thermal capacity of the sample, T_1 is the temperature near the heat source and T_2 is the temperature near the heat sink, D is the thickness (m) and A is the area (m^2) of the specimen and λ is the thermal conductivity of the specimen. Now considering that the heat supply is constant and if the values of $-\frac{C_p}{4}\frac{d\left(T_1 + T_2\right)}{dt}$ are plotted against values of $\frac{A(T_1 - T_2)}{D}$, then the slope of the line will give the value of thermal conductivity and the intercept will be the rate of heat input (Q_1). An example of the use of spreadsheet for these calculations is shown in Fig. 7.

STATISTICAL ANALYSIS

In spreadsheets various statistical functions are available, which can be used for statistical analysis of the experimental data. An example of Analysis of Variance (ANOVA) for multiple comparison of the CM Factor, a parameter used for assessing wood-cement compatibility, is shown in Fig. 8 [10]. For the post-hoc analysis the Excel Add-In of Keller [13] were used because Excel does not have this function. The results were comparable with those obtained from the commercial statistical software.



ANOVA CM FACTOR (10% ADDITION LEVEL)

MDMS	MDLS	LDMS	LDLS	HDSS
0.63	0.61	0.53	0.56	0.44
0.62	0.58	0.52	0.63	0.47
0.63	0.59	0.54	0.49	0.43

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MDMS	3	1.8730276	0.624342532	1.95664E-05
MDLS	3	1.7774958	0.592498603	0.000177584
LDMS	3	1.5817663	0.527255417	0.000134414
LDLS	3	1.6818449	0.560614973	0.004601548
HDSS	3	1.3399153	0.446638434	0.000288917

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0559386	4	0.013984639	13.39004194	0.0005026	3.4780498
Within Groups	0.0104441	10	0.001044406			
Total	0.0663826	14				

Result: Sign. Diff. F>Fcrit

SR Karade:
.005 DUE TO
BONFERRONI'S
CORRECTION

LSD & Tukey Tests

Multiple Comparisons

			Critical value		Conclusion	
			LSD	Omega	LSD	Omega
Treatment	Treatment	Difference	Alpha = 0.005	Alpha = 0.05		
MDMS	MDLS	0.0318	0.0945	0.0868	-	-
	LDMS	0.0971	0.0945	0.0868	Sign. Diff.	Sign. Diff.
	LDLS	0.0637	0.0945	0.0868	-	-
	HDSS	0.1777	0.0945	0.0868	Sign. Diff.	Sign. Diff.
MDLS	LDMS	0.0652	0.0945	0.0868	-	-
	LDLS	0.0319	0.0945	0.0868	-	-
	HDSS	0.1459	0.0945	0.0868	Sign. Diff.	Sign. Diff.
LDMS	LDLS	-0.0334	0.0945	0.0868	-	-
	HDSS	0.0806	0.0945	0.0868	-	-
LDLS	HDSS	0.1140	0.0945	0.0868	Sign. Diff.	Sign. Diff.

Conclusion :MDMS and LDMS are significantly different, but MDLS and D are not. However, E is significantly different with all at 10 % level except with LDMS. Particle size does not make effect, except if it becomes powder. density may make difference at medium size.

Figure 8 Statistical analysis for multiple comparison of samples in spreadsheet

CONCLUSION

The paper demonstrates that spreadsheets have wider applications in building materials research, which include import and export of experimental data; evaluation of mechanical properties, surface area, heat of hydration, thermal conductivity; optimisation of mixes and particle grading and statistical analysis. The use of spreadsheets is very convenient, but has some limitations in plotting charts and in statistical analysis, which can be supplemented with Add-Ins.

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