Optimisation of Water-Cement Ratio for Determination of Wood-Cement Compatibility

S.R. Karade*

Central Building Research Institute, Roorkee-247667 (India)

A version of this paper has been published in *Proc. 9th NCB International Seminar on Cement and Building Materials,* New Delhi. Vol.2, 2005, VI:353-360.

* Email: srkarade@rediffmail.com

Optimisation of Water-Cement Ratio for Determination of Wood-Cement Compatibility

S.R. Karade[*]

Central Building Research Institute, Roorkee-247667 (India)

Abstract

Wood and other lignocelluosic materials are used in various forms such as aggregate, flakes, chips and fibres for making composites. These composites have several building applications, which are increasing day by day. It is has been found that many species of wood retard the setting of cement. The degree of retardation depends upon several factors like cutting season of wood, storage period, moisture content, and geometrical parameters of the wood particles. Thus, a test, called hydration test, is often conducted to assess the compatibility of wood with cement. In this test, a certain quantity of wood particles is mixed with cement and then with water in a polyethylene bag. The bag is then kept in an insulated flask and the change in temperature of the mix is recorded over a period, generally 24 hours. The hydration curve of this mix is then compared with a hydration curve of neat cement to assess the wood-cement compatibility. In this test the amount of water mixed is an important variable. Its requirement changes with the quantity of wood, type of wood and shape and size of particles. It is often confusing how much water should be added for a given sample. No standard method is available so far for such test. In this paper a method has been suggested to optimise the water requirement for wood-cement compatibility assessment test. Experimental data have been presented from the study carried out by varying particle size and concentration of cork granules and water-cement ratio.

1. INTRODUCTION

Various lignocellulosic materials like wood, natural fibers, cork, agro-forestry wastes in numerous forms are being used alongwith cement for making composite materials. They are mainly used for making pre-cast building products like external cladding, protective elements for fireproofing, sound insulation, specialised flooring, partition, roofing tiles, masonry blocks, and others. Considerable research in this area has been done in the last 40 years because of the growing concern about the health hazards associated with the use of asbestos fibre (Coutts, 1988; Moslemi, 1999) and to develop low cost alternative building materials from the locally available resources. In the initial stages of the research it was realised that all the lignocellulosic materials are not suitable for making composites with cement because some of them hinder the cement hydration process (Sandermann *et al.*, 1960; Weatherwax and Tarkow, 1964). It was also found that the retardation effect of wood with cement changes within a species dependent on location and soil (Hachmi *et al.*, 1990) and part of the tree (Miller and Moslemi, 1991). The main cause of the inhibition is the presence of organic compounds like sugar and tannin in the particles. Therefore, to assess the suitability of the wood various attempts have been made. The methods were based on the measurement of hydration characteristics of a wood-cement mix (Sandermann and Kohler 1964; Weatherwax and Tarkow 1964; Hachmi *et al.*, 1990); the comparison of the mechanical properties of wood-cement mixes (Hong and Lee 1986; Lee *et al.* 1987; Demirbas and Aslan 1998); and the visual assessment of microstructural properties of the wood-cement mixes (Ahn and Moslemi, 1980; Davies *et al.*, 1981).

[*] Email: srkarade@rediffmail.com

The measurement of hydration temperature of a wood-cement mix is found to be convenient because of its simplicity. However, presently there is no standard method available for measuring the hydration temperature of wood-cement mixes. To measure the hydration temperature wood, cement and water are first mixed in a predetermined ratio and the mix is then kept in a thermally insulated container. The temperature of the mix is recorded at suitable intervals over a period, generally 24 hours. A comparison is then made between the hydration characteristics of a wood-cement mix and a neat cement sample in order to assess the wood-cement compatibility.

For compatibility assessment a similar wood:cement:water ratio of either 20:200:100 or 15:200:90.5, which were initially suggested by Sandermann and Kohler (1964) and Weatherwax and Tarkow (1964), respectively are used. The wood particle size for these tests is generally very fine. For example, Weatherwax and Tarkow (1964) used 0.1 to 0.25 mm size, whilst Hachmi *et al.* (1990) used 0.425 to 0.85 mm size particles. Weatherwax and Tarkow (1964) calculated the required amount of water for their hydration tests to be 0.25 ml per gram of cement and 2.7 ml per gram of wood, which appears to be a rule of thumb, and several researchers have followed it subsequently. For example see: Biblis and Lo (1968); Zhengtian and Moslemi (1985); Lee *et al*. (1987) and Hachmi *et al.* (1990). It must be noted that these parameters have very limited practical relevance because, in practice, much higher wood:cement ratios and larger particles are used. These parameters may be suitable for comparing the compatibility of different wood species at a small concentration and with same particle size, but cannot be used for other compositions. For example, to know the maximum concentration of wood that can be added to cement without affecting its hydration or to assess suitability of wood particle sizes. A fixed water:cement ratio is generally used for all wood species. However, different species absorb different amounts of water such that a variable amount of free water may be available for cement. It appears that there is no logical base to relate the water requirement with the composition. Lack of water can reduce the maximum temperature, while excess water can delay the peak. Furthermore, these methods based on maximum hydration temperature do not give consistent results, because of various limitations, which are discussed elsewhere (Karade *et al.,* 2003). In view of this an alternative method for optimisation of water requirement for the wood-cement compatibility assessment method has been suggested in this paper with an example.

2. PROPSOED METHOD

During the wood-cement compatibility assessment using hydration test, water is consumed by three main processes: i) cement hydration, ii) absorption by wood particles and iii) wetting of wood particle surfaces. The water requirement for cement hydration can be optimised by varying the w/c ratio and determining the C_M factor, which can be calculated using the following relationship.

$$C_M = \sqrt{\frac{Q_{emax}}{t_{e\,max}}} \qquad [1]$$

Where Q_{emax} is the maximum heat evolution rate and t_{emax} is the '*equivalent time'* taken to reach Q_{emax}. These parameters are computed using a maturity function. The calculation procedure has been described in Karade *et al*. (2003). The w/c ratio at which the value of C_M factor is highest can be used as water requirement for cement during the compatibility assessment test. In the present case the optimum w/c ratio required for cement was 0.35 as can be seen in Figure 1.

During an investigation (Karade, 2003) it was proposed to use five different grades of waste cork granules for making cement-bonded composites. For assessment of their compatibility with cement at different concentration the water requirement was not known. To determine it two grades of cork granules — medium density, medium size (MDMS) and high density, small size (HDSS) — were considered. Their properties are reported in Table 1. The '*apparent water absorption'* of cork granules was determined by stirring cork granules in water for 30 min and then removing the free surface water with a wet cloth. Subsequently, the moisture content of the cork granules was measured as the '*apparent water absorption'* by oven drying at 103±2 ºC. These values appear to be high, but water absorptions of 80 and 300% have been reported for lightweight aggregates like pumice and vermiculite, respectively (Cheng and Lee 1986). C_M factor for these cork granule-cement mix in the ratio of 10:100 was determined using various w/c ratios. As shown in Figure 2, the highest value of C_M factor for MDMS cork is at w/c ratio of 0.45 and that for HDSS is at w/c ratio of 0.55.

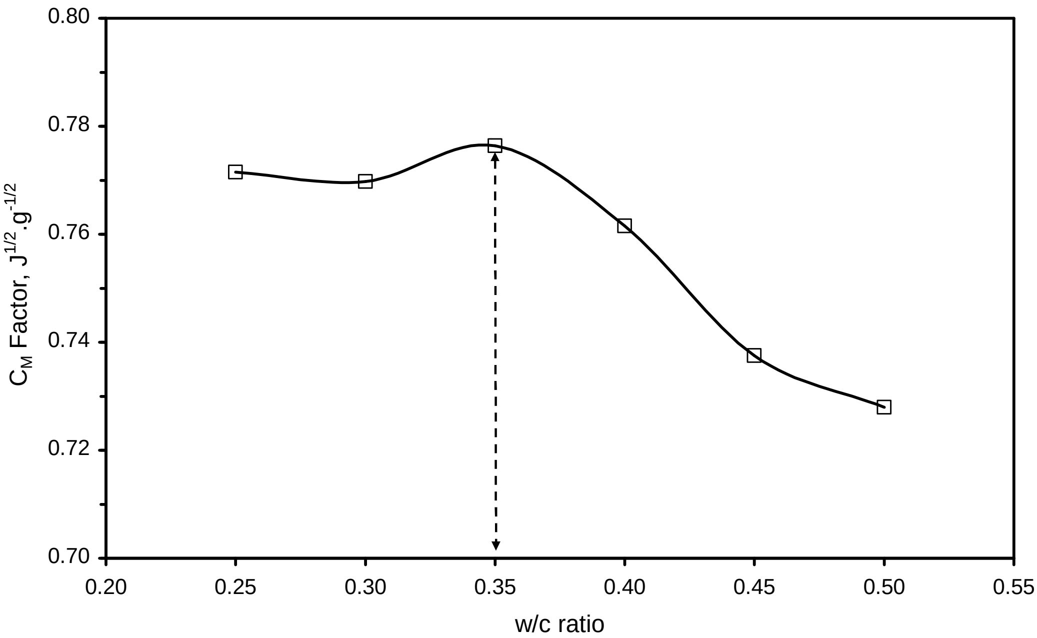

Figure 1 Effect of w/c ratio on C_M factor of cement.

Table 1 Physical properties of cork waste granules.

Type of cork granules	Bulk density (kg/m^3)	Granule density (kg/m^3)	Apparent water absorption (%, wt.)	Mean granule size, mm	Specific surface area (cm^2/g)
Medium Density, Medium Size (MDMS)	171	391	100	0.8	401
High Density, Small Size (HDSS)	280	583	200	0.1	2127

Considering that the optimised w/c ratio for cement is 0.35 and that the *apparent water absorption* values for MDMS and HDSS corks are 100% and 200%, respectively, the following formula is proposed to calculate the water requirement for different grades of cork at different concentrations.

$$W_w = 0.35W_c + \frac{A_w W_g}{100} \quad [2]$$

where W_w is the total weight of water required; W_c and W_g are weight of cement and weight of oven dry cork granules in the mix, respectively, and A_w is the *apparent water absorption* of cork granules in percent by weight.

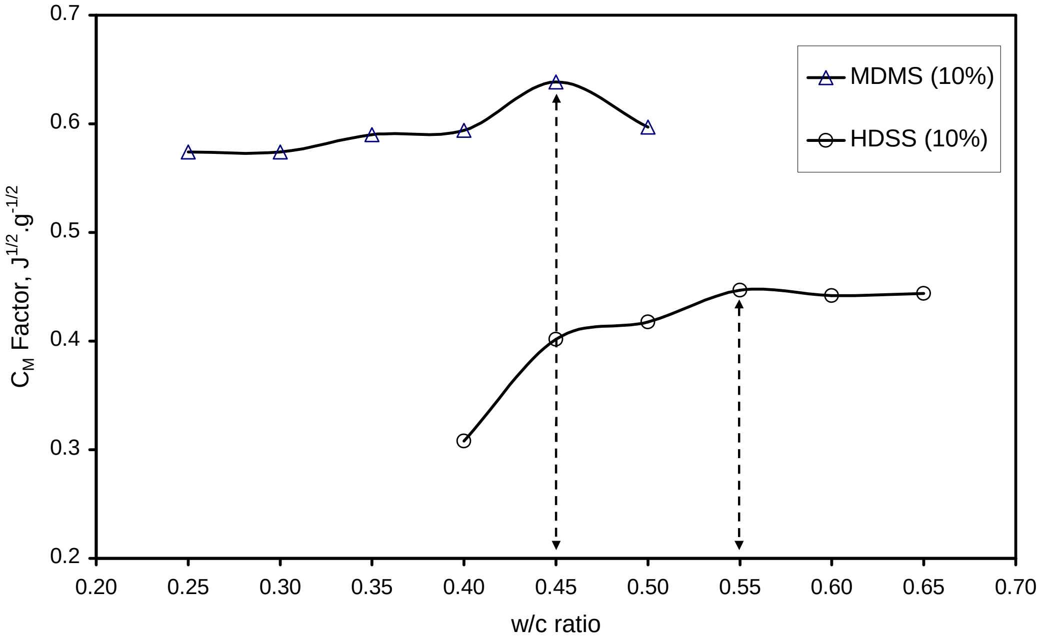

Figure 2 Selection of optimum w/c ratio for the highest C_M factor of cork-cement mix containing 10% cork granules by weight of cement.

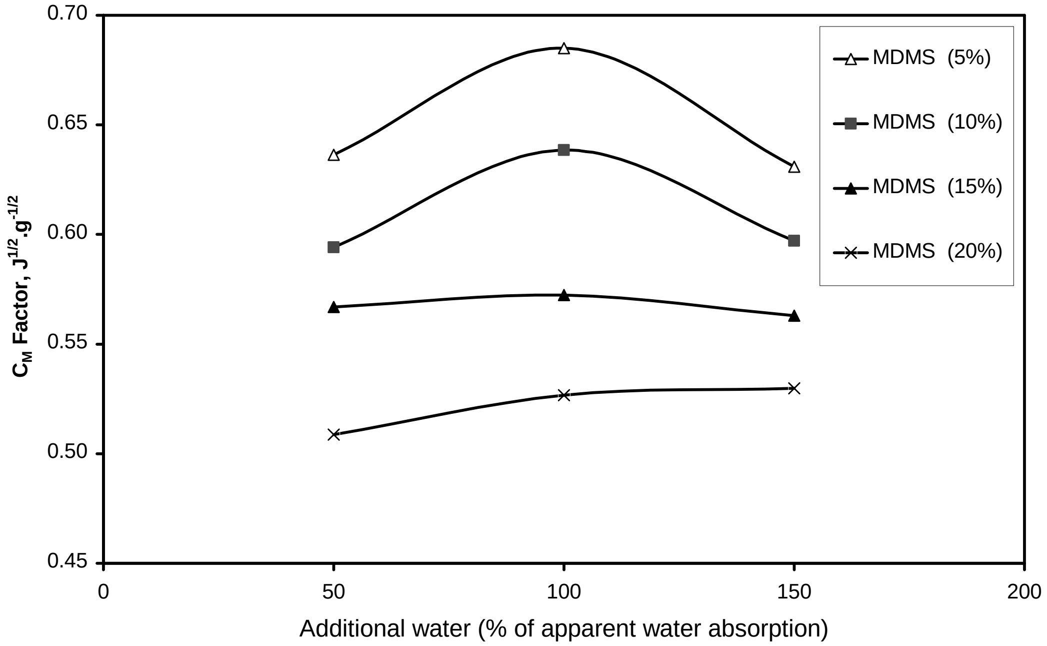

Figure 3 Optimisation of additional water requirement for MDMS cork.

To check the validity of Equation [2] an additional experiment was conducted in which the w/c ratios were changed for mixes containing various addition levels of MDMS. The results are shown in Figure 3. Results show that the highest value of C_M factor generally coincides with the W_w calculated using Equation [2] i.e. when the mix contained water equal to 0.35 times the weight of cement plus the weight of water that can be apparently absorbed by the cork. Thus, during a wood-cement compatibility assessment test besides the water required for cement hydration, water demand for wood particles is equal to their *apparent water absorption* value.

3. CONCLUSION

For assessment of wood-cement compatibility hydration tests are conducted. For these tests generally a wood:cement: water ratio of 15:200:90.5 is used, which appears to be a rule of thumb and not an optimised one. For compatibility assessment at different wood concentration, there has been no basis established yet to determine the water requirement. A method has been proposed in this paper, which relates the total water requirement with the water required for cement hydration and *apparent water absorption* of wood particles. With experimental data using cork granules it has been shown that the method is applicable at different cork: cement ratios.

4. ACKNOWLEDGEMENT

The reported work is a part of the study conducted for a Doctorate Degree at Buckinghamshire Chilterns University College (BCUC), High Wycombe (UK). The author thanks the Director, Central Building Research Institute (CSIR), Roorkee (India) for grant of study leave and to BCUC for providing financial support to undertake this study. The author is also grateful to his supervisors Drs Mark Irle and Kevin Maher for their guidance.

5. REFERENCES

Ahn, W.Y. and Moslemi, A.A. 1980. SEM examination of wood-Portland cement bonds. Wood Sci .*13*(2), 77-82.

Biblis, E.J. and LO, C. 1968. Sugar and other wood extractives: Effect on the setting of southern pine –cement mixes. For. Prod. J. *18*(8), 28-34.

Cheng, C.L. and LEE, M.K. 1986. Cryogenic insulating concrete—Cement based concrete with polystyrene beads. ACI Journal *83*, 446-454.

Coutts, R.S.P. 1988. Wood fibre reinforced composites. In: Natural Fibre Reinforced Cement and Concrete. Ed. R.N. Swamy. Blackie and Sons Ltd. Glasgow. pp.1-62.

Davies, G.W., M.D. Campbell and R.S.P. Coutts. 1981. A S.E.M. study of wood fibre reinforced cement composites. Holzforschung *35***,** 201-204.

Demirbas, A. and Aslan, A. 1998. Effects of ground hazelnut shell, wood and tea waste on the mechanical properties of cement. Cement Concrete Res. *28*(8), 1101-1104.

Hachmi, M., Moslemi, A.A. and Campbell, A.G. 1990. A new technique to classify the compatibility of wood with cement. Wood Sci. Technol. *24*(4), 345-354.

Hong, Z. and Lee, A.W.C. 1986. Compressive strength of cylindrical samples as an indicator of wood- cement compatibility. For. Prod. J. *36*(11/12), 87-90.

Karade, S.R. 2003. An Investigation of Cork-Cement Composites. PhD Thesis. Brunel University (UK).

Karade, S.R., Irle, M.A. and Maher, K. 2003. Assessment of Wood-Cement Compatibility: A New Approach. Holzforschung., 57(6):672-680.

Lee, A.W.C., Hong, Z. Phillips, D.R. and Hse, C.Y. 1987. Effect of cement/wood ratios and wood storage conditions on hydration temperature, hydration time, and compressive strength of wood-cement mixtures. Wood Fiber Sci. *19*(3), 262-268.

Miller, D.P. and Moslemi, A.A. 1991. Wood-cement composites: species and heartwood-sapwood effects on hydration and tensile strength. For. Prod. J. *41*(3), 9-14.

Moslemi, A.A. 1999. Emerging technologies in mineral-bonded wood and fibre composites. Advanced Performance Materials *6*, 161-179.

Sandermann, W. and Kohler, R. 1964. Studies on mineral-bonded wood materials. IV. A short test of the aptitudes of woods for cement-bonded materials. Holzforschung *18*, 53:59.

Sandermann, W., Preusser, H. and Schweers, W. 1960. The effect of wood extractives on the setting of cement-bonded wood materials. Holzforschung *14***,** 70-77.

Weatherwax, R.C. and Tarkow, H. 1964. Effect of wood on setting of Portland cement. For. Prod. J. *14*(12), 567-570.

Zhengtian, L. and Moslemi, A.A. 1986. Effect of western larch extractives on cement setting. For. Prod. J. *36*(1), 53-54.