CORRELATION BETWEEN DISCRETE ELEMENT PARAMETERS AND BINGHAM COEFFICIENTS OF MORTAR

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1. Introduction

In this paper, effort has been made to correlate the Discrete Element Model (hereafter, DEM) [1] parameters of the simulation with the Bingham coefficients of high flow mortar. Here, Bingham coefficients mean yield value (τ_0) and viscosity (η). Lifting Sphere Viscometer test has been employed to calculate the Bingham coefficients. A Detail description of the methodology is provided in the later sections of the paper. In this paper, only the effect of viscosity and overlap between elements has been considered. Change of overlap, between elements, gives different stiffness value in the model. The relationship, between Bingham coefficients with these two DEM parameters, has been plotted and described in detail in the paper.

2. Dem Model

Two-phase model, in different particles, has been used to model the fresh concrete. One particle is used as aggregate and another particle as mortar. The constitutive model of DEM, used in this paper is different from the constitutive model, that authors have used in the qualitative simulation. Detail description of the former constitutive model can be found in Noor and Uomoto [2, 3]. In the present constitutive model, strain softening is included in the tension model. In this model, tensile force carried by mortar, will increase to a peak value and then drop down to zero. The increasing and decreasing rate of force after peak depend on unloading stiffness. And if the tensile force becomes zero the contact between the particle breaks. Allowance of tension is determined from the experiment. Linear viscous model for both normal and tangential direction has also been included.

3. Methodology

Different sets of DEM parameters are taken for numerical simulation with same choices of lifting sphere ball speed (v). Therefore, the numerical simulation is time consuming and exhaustive. In this paper, ratio between normal stiffness and shear stiffness is kept constant. Only the overlap is varied to observe its effect on rheology value. Viscosity parameter has been examined in detail. In first case, ratio between both direction is kept constant and different normal viscosity values have been used. In second case, normal direction viscosity is kept to a constant value and the ratio between normal direction and shear direction (hereafter, N/S) has been changed. The dragging force-displacement curve is plotted at each lifting speed from the numerical simulation as shown in Fig. 1.

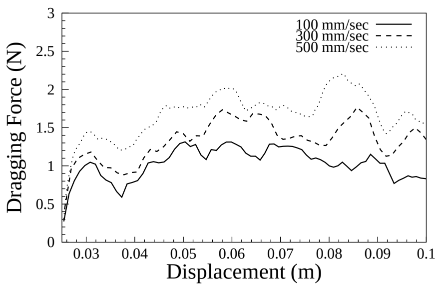

Figure 1: Force-displacement curve for lifting sphere viscometer test.

The determination of Bingham coefficients from results of numerical simulation is similar to that of experimental one. Firstly, the resistance F to pulling ball is calculated by averaging the dragging force within the whole displacement range after the peak, for each lifting speed. A set of points are plotted with $v/2r$ as ordinate and $F/12\pi r^2$ as abscissa, for each set of parameters. Here, r is the radius of lifting sphere. Least squares is applied to obtain linear approximation of Bingham coefficients with the slope of approximated line representing viscosity η and intercept with abscissa representing yielding value τ_0. Fig. 2 shows the linear approximation of points calculated from simulation results for one typical case of viscosity. By treating DEM parameters, including overlap parameter, viscous coefficient and viscous ratio, as independent variables and Bingham coefficients as dependent variables different figures have been plotted to show their variation.

The main objective of this paper is to get quantitative parameters for mortar simulation. Then, these parameters will be combined with the parameters of aggregates to perform the concrete simulation. After completing the whole process it would be possible directly to simulate any high flow concrete with this model from the fresh concrete parameters – such as mix design and Bingham coefficients.

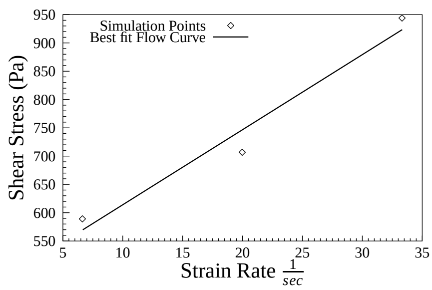

Figure 2: Numerical flow curve for a typical case.

4. Parametric Study

A considerable simulation, of lifting sphere viscometer test, has been performed in order to investigate the relationship between DEM parameters and Bingham coefficients. The various parameter values that have been used in the simulation is given in the Table 1. After Bingham coefficients for each set of parameters are determined, the relationship between DEM parameters and Bingham coefficients can be explained as follows.

To observe the effect of overlap, its value has been changed from 1.0 to 5.0 percent. If the value greater than 5.0 percent is used the overlap between the element becomes too large that they may pass each other. The relation between overlap and

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Table 1: Parameter values used for the simulation

Parameters Name	Value Used	Comment
Peak Value for Tension	0.015 (N)	Constant for all cases
Ratio between Normal and Shear Viscosity (N/S)	1.0	Constant NV varied
Overlap between elements	1.0 %	Constant when N/S varied
Normal Viscosity(NV)	0.05 (N-s/m)	Constant when N/S varied
Ratio between Normal and Shear Stiffness	1/10	Constant for all cases

Bingham coefficients have been shown in Fig. 3. As seen in Fig. 3, the increment of overlap percentage results in the exponential decay of the both yield value and viscosity. This is because, increase of overlap percentage decreases the normal stiffness value. It can be observed from the figure that after some certain value, overlap does not have any effect on yield and viscosity value. However, the influence of overlap percentage is not so significant on viscosity.

The viscous parameter is divided into two main parts. The variation of normal and shear viscosity, with their ratio 1, is the first case. The variation of normal and shear viscosity ratio is the second case. This case is further divided into two parts. When ratio between normal and shear viscosity is greater than one and when N/S is less than one. For this case the normal viscosity is always fixed and the value of the shear viscosity depend on the N/S ratio. Fig. 4 shows the variation of Bingham parameters with viscosity value. It is seen that, with the increase of the viscosity both yield and viscosity values increase. The increment is linear for yield stress but is exponential in the case of viscosity. Fig. 5 shows the effect of normal to shear viscosity ratio when it is less than one. It is seen, that yield stress increases with the increase of the ratio but opposite is observed in the case of viscosity. Both variations are linear. The variation of N/S ratio when it is greater than one is shown in Fig. 6. With the increase of the N/S ratio both yield and viscosity decreases, but viscosity decreases faster and becomes constant after some value. The decay is exponential for the viscosity but linear for the yield value.

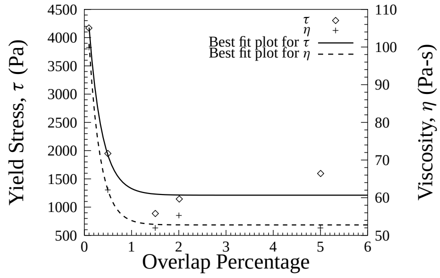

Figure 3: Relation of overlap with Bingham coefficients.

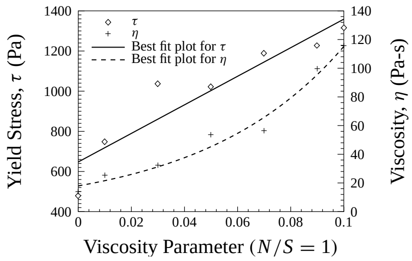

Figure 4: Relation of viscosity with Bingham coefficients for constant N/S.

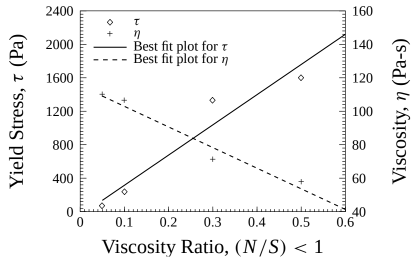

Figure 5: Relation of N/S (<1) with Bingham coefficients.

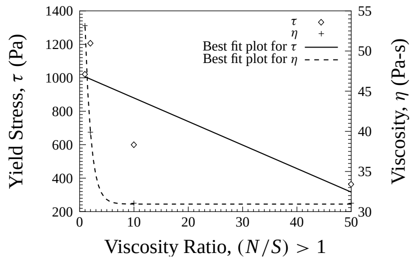

Figure 6: Relation of N/S (>1) with Bingham coefficients.

5. Conclusion

In this paper, attempt has been made to observe the variation of Bingham coefficients with the variation of some selected DEM parameters. Same methodology will be followed to determine the effect of other DEM parameters. Then some model will be established to get the DEM parameters from the mortar as well as concrete mix proportion. From the above discussion, it can be said that the modified DEM model can simulate the behavior of fresh mortar in lifting sphere viscometer test quantitatively. Viscosity parameter affects the viscosity of the mortar significantly but not the yield value. And it is also found that overlap percentage affects the yield value of mortar significantly but not the viscosity. It is observed that, in all cases the yield value is very high. The actual yield value of high flow mortar is lower than these values [4]. This indicates the fact that, it is difficult if not impossible to simulate the high flow mortar behavior with the discrete element method. But, these values are very near the yield values of the Self-compacting concrete [4]. So, combination of mortar particle and aggregate particle in DEM simulation should produce the concrete behavior quantitatively.

References

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