V－108

NUMERICAL SIMULATION OF DRAGGING BALL VISCOMETER EXPERIMENT

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1. INTRODUCTION

In this paper the efforts are continued to improve the DEM model in order to simulate the behavior of fresh concrete in dragging ball viscometer more precisely compared with the results obtained in paper [1]. The new modeling of interaction between mortar and coarse aggregate incorporates the displacement- adhesion curve based on the adhesive test of mortar. Moreover the relationship between Bingham coefficients with DEM parameters as spring constants, dasphot coefficients, friction and allowance of tension was diagrammatized.

2. DEM MODEL

DEM element for fresh concrete is a composite structure consisting of coarse aggregate as skeleton with mortar as surrounding binder. The interaction among DEM elements includes elastic force, damping force etc. [2]. The displacement-force relation can be illustrated in Fig. 1.in which tensile part can be evaluated by adhesion test of mortar. In case of compression, within the limit of mortar layers the contact force increases at a small magnitude of rate, whereas beyond this threshold r_0, namely, the two skeletons are coming into contact, the force will increase at a very large rate. On the contrary, in case of tension the tensile force supported by mortar will increase to a peak value and then drop down to zero if fracture of binder happens, which means that allowance of tension is exceeded. The increasing and decreasing rate of curve of tensile part, that is, the shape of the curve is dependent on the adhesive properties of mortar. To reflect the relationship of Fig. 1 into DEM parameters, Fig. 2 shows the determination of DEM parameters connected with relative displacement δ. Here DEM parameters mean spring constants of both normal and tangential direction and dashpot coefficients of both directions respectively. The DEM parameters can be written as follows:

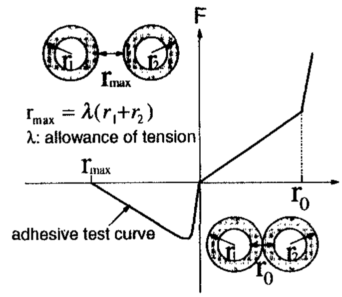

Fig. 1 Relationship of relative displacement and force

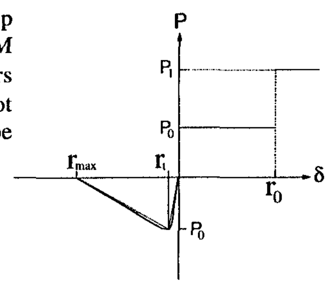

Fig. 2 Relation of DEM parameters with displacement

$$\text{Compression:} \begin{cases} P = P_0 & (\delta < r_0) \\ P = P_1 & (\delta \geq r_0) \end{cases} \tag{1}$$

$$\text{Tension:} \begin{cases} P = \frac{p_0 \delta}{r_t} & (\delta < r_t) \\ P = \frac{r_{max} - \delta}{r_{max} - r_t} P_0 & (\delta \geq r_t, r_{max} = \lambda(r_1 + r_2)) \end{cases} \tag{2}$$

where
P: DEM parameters including spring constants of both normal and tangential directions and dashpot coefficients of both directions respectively; P_0: Threshold value of DEM parameters; δ: Relative displacement of two elements in contact; r_0: Sum of depth of mortar layers of two elements; r_1,r_2: Radii of two elements respectively; r_t: Relative displacement at which tensile force reaches to the maximum value; λ: Allowance of tension; r_{max}: Threshold value of separation of two elements beyond allowance of tension.

3. COMPARISON OF RESULTS

Table 1 A set of parameters for DEM model

Spring constant Normal K_n at P_0	1.2kgf/mm	Friction coef. of particles μ_p	0.4
Spring constant Tangential K_s at P_0	0.3kgf/mm	Friction coef. of wall and particle μ_{wp}	0.4
Dashpot coef. normal η_{dn} at P_0	5.7×10^{-4}kgf·s/mm	Allowance of spring tension λ	1%
Dashpot coef. Tangential η_{ds} at P_0	7×10^{-4} kgf·s/mm	Time ctep Δt	10^{-5}s
Particle no. Nel	286	Simulation time T	4.0s

Hereinafter a set of parameters used in 2D DEM simulation is listed in Table 1. A more detailed description of DEM method and physical sense of parameters can be found in literature [2]. A comparison is made between the simulation result obtained using previous model in literature [1] and that by new model as shown in Fig. 3. Although there is discrepancy between the experimental result with numerical one, it is seen that the simulation result obtained using new model is improved and in quite good agreement with the experimental one compared with the one using previous model.

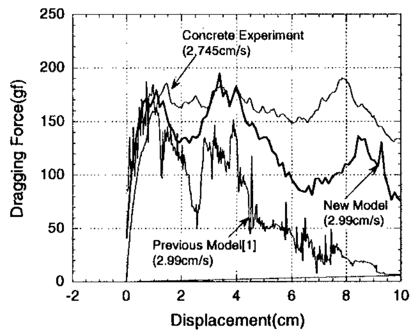

Fig. 3 Comparison of simulation and experimental result

4. PARAMETRIC STUDY

A considerable simulation of dragging ball viscometer test has been carried out in order to investigate the relationship between DEM parameters with Bingham coefficients including yielding value and viscosity. For simplicity spring constants of two directions are varied at the same rate and so for dashpot coefficients of two directions. Here the nomenclature is made to symbolize η representing Bingham viscosity while η_{dn} representing DEM dashpot coefficient. Moreover spring constants and dashpot coefficients are altered based on initial value respectively. The base value for spring constant K=1 means that spring constant normal K_n equals to 0.03 kgf/mm and spring constant tangential K_s is 0.0075kgf/mm. Following the same rule the base value for dashpot coefficient η_d=1 is defined as η_{dn} =5.7×10^{-5} kgf.s/mm and η_{ds}=7.0×10^{-5}kgf.s/mm. To illustrate their effects on Bingham coefficients only the relative values are given. Here spring constants, dashpot coefficients, allowance of tension and friction coefficient are taken to investigate their influences on yielding value and viscosity in Fig. 4 to Fig. 7.

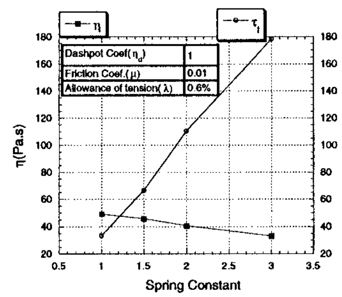

Fig. 4 Relation of spring constant with Bingham coefficients

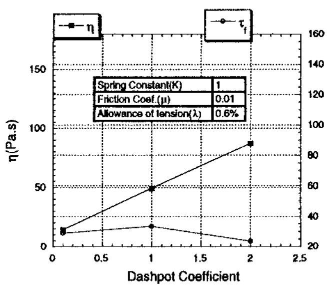

Fig. 5 Relation of dashpot coefficient with Bingham coefficients

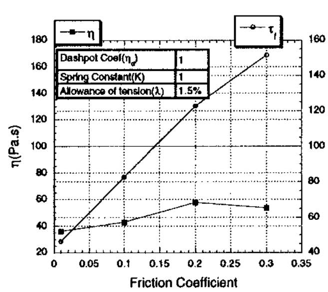

Fig. 6 Relation of friction coef. with Bingham coefficients

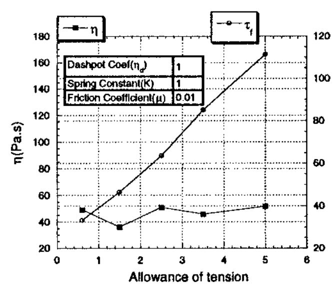

Fig. 7 Relation of allowance of tension with Bingham coefficients

5. CONCLUSION

From the above description the following conclusions can be drawn:

1. The modified DEM model can simulate the behavior of fresh concrete in dragging ball viscometer test with rather high precision which further proves the applicability of DEM to simulate the behavior of fresh concrete.
2. The increase of allowance of tension will lead to nearly linear increase of yielding value but exert less effect on viscosity. Spring constant and friction coefficient are quite correlated with yielding value but show less influence on viscosity. Dashpot coefficient illustrates significant effect on viscosity but take less influence on yielding value.

6. REFERENCE

1. Chu, H., Machida, A. and Kobayashi, H.,"Verification of Application of DEM to Fresh Concrete by Sphere Dragging Viscometer", Proceedings of JCI, 1997(under publish).
2. Chu, H., Machida, A. and Iwashita, K.,"Two Dimensional Numerical Simulation of Flow Behavior of Fresh Concrete by DEM Method", Proceedings of the 50th Annual Conference of JSCE, 5, 1995, pp1026-1027.