USING DEM SIMULATION TO OBSERVE THE VARIATION OF SHOTCRETE MIX PROPORTION AND REBOUND RATIO DURING SHOOTING

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1 INTRODUCTION

In this research, a three-dimensional numerical analysis using Distinct Element Method [1] (hereafter, DEM) was utilized to model the shotcrete process, considering various conditions of materials and shooting, such as air pressure and flow, water-cement ratio, accelerator, etc. Bond value of mortar was found to be an important factor to the rebound of shotcrete. The variations of shotcrete mix proportion during shooting and of rebound ratio with shooting volume were considered. The calculated result shows a qualitative image of actual shooting mechanism.

2 FUNDAMENTAL CONCEPTS

The DEM was introduced by Cundall (1971) for the analysis of rock and then applied to soils by Cundall and Track (1979). In the DEM, the interaction of the particles is treated as a dynamic process with states of equilibrium developing whenever the internal forces balance. In this research, simulation of shotcrete was carried out using single-phase particles model: mortar and coarse aggregate were modeled by two separate groups of particles. A viscous-damping and bond model was used to treat the contact of particles [Fig. 1].

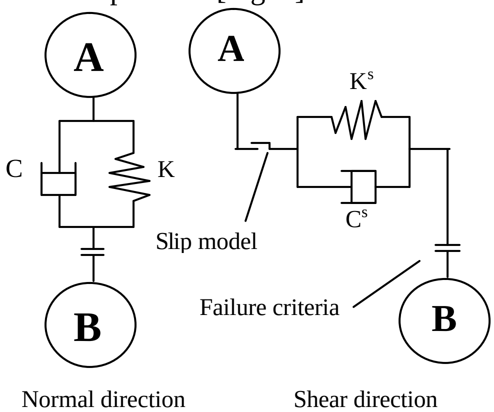


Figure 1. Viscous damping contact model. A and B are two ball in contact, K and C are spring and daspot, respectively.

SIMULATION PROCEDURE

3.1 Simulation outline

Parametric study was carried out to obtain the DEM parameters of fresh shotcrete at the beginning of simulation. Size of balls, their stiffness, density, etc. were given as initial condition. Shooting velocity was applied to concrete particles at the nozzle to shoot them to the target wall. On the way to the target wall, the effect of accelerator was considered using the model proposed by Puri [3]. Finally, the rebound ratio and porosity were evaluated. Figure 2 shows a view in simulation with shooting distance of 1.5m. Dark particles represent coarse aggregate and the others are mortar.

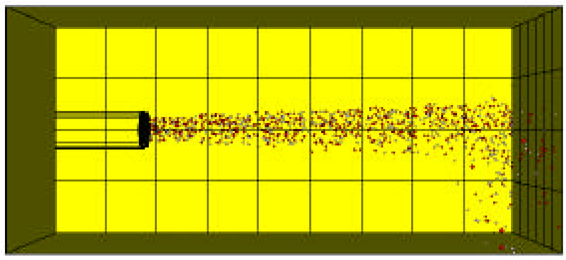


Figure 2 A view in shotcrete simulation. Each cell has the size of 20cm x 20cm.

3.2 Mortar by coarse aggregate ratio

In this paper, the authors used the term ***Mortar by Coarse Aggregate Ratio*** to express the ratio by volume between mortar and coarse aggregate. It was assumed that there is no bonding between coarse aggregate particles themselves, while the bond exists wherever mortar particles are involved [4]. Simulation was carried out to consider the effect of mortar by coarse aggregate [5], and the effect of bond value on the rebound ratio. In addition, the variation of rebound ratio with respect to shooting volume and the actual mix concrete proportion after shooting were also the target of this simulation.

4 RESULTS AND DISCUSSIONS

In Figure 3, it is clear that the larger the mortar by coarse aggregate (M/C) ratio, the smaller is the rebound loss. However, at a certain value of M/C ratio, around 5, the increase in M/C ratio will hardly affect the rebound of shocrete.

Mortar particles act as bonding agent which attaches coarse aggregate to the target wall. Therefore, bond values of mortar play very important role in the rebound of shocrete. The larger the bond value, the lower the rebound ratio. However, too large bond value results in bad compaction and high porosity (Fig. 4).

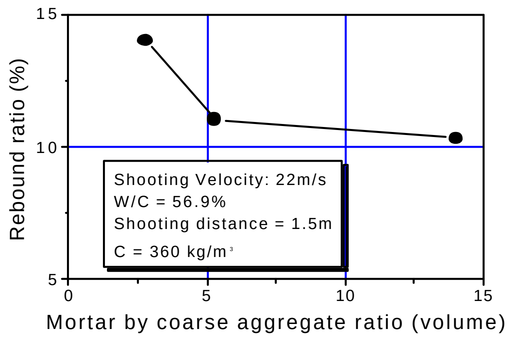


Figure 3. Effect of mortar by coarse aggregate ratio on rebound ratio

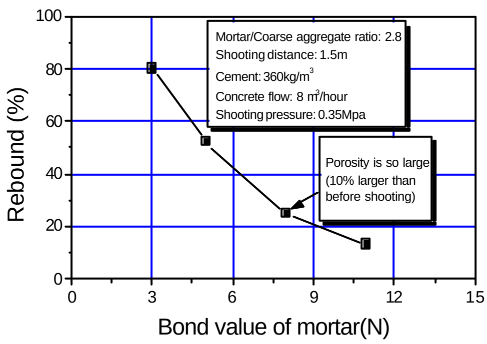
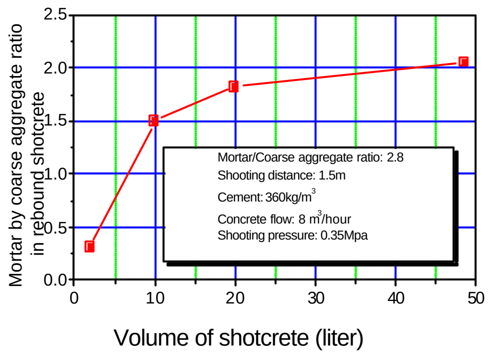


Figure 4. Effect of bond value of mortar (in normal direction) on the rebound ratio



Figgure 5. Variation of concrete proportion

The most advantageous point of this model is that the difference in rebound rate of coarse aggregate and mortar can be considered at the beginning of shooting, almost 100% of coarse aggregate drop to the ground, so rebound concrete contains mainly coarse aggregate. However, after a thick layer of mortar has been formed on the wall, the rebound coarse aggregate begins to stick to the wall via that mortar layer (Fig. 5). The total rebound ratio of concrete can be as high as 62% at the beginning due to large rebound of coarse aggregate. However, the rebound decreases gradually at higher shooting volumes (Fig. 6). The results in Figures 5 and 6 indicate that when measuring the rebound of shotcrete, the shooting volume should be large enough to ensure the accuracy.

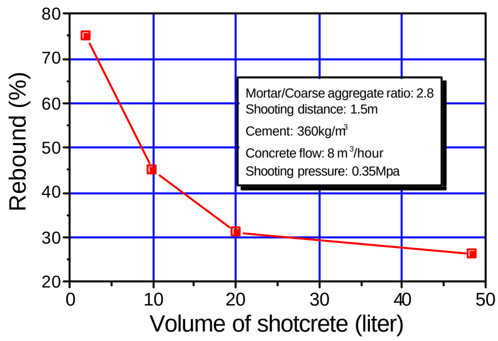


Figure 6. Variation of rebound ratio with shooting volume.

5 CONCLUSIONS

- Bond value and mortar by coarse aggregate ratio play important roles in the rebound of shotcrete.
- It is able to point out from simulation that the measurement of rebound must be carried at a suitable volume to ensure the accuracy.
- Model with single-phase particles enables the consideration of different rebound ratios for mortar and coarse aggregate.

5 REFERENCES

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