Comparison between YADE simulations and DEM (PFC3D) simulations for the Benchmark tests for verifying discrete element modelling codes at particle impact level

➢ **Test 1**: Elastic normal impact of two identical spheres

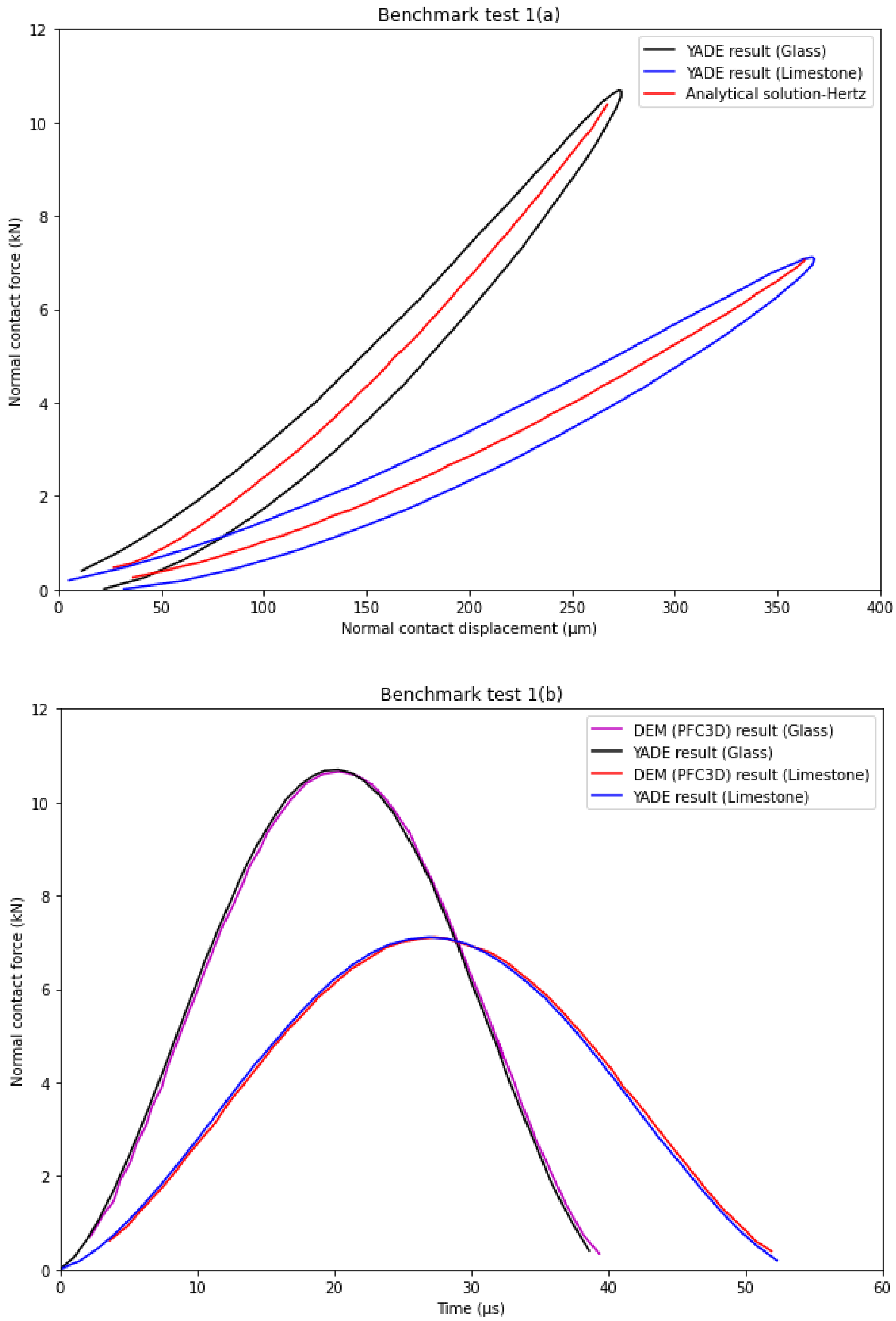
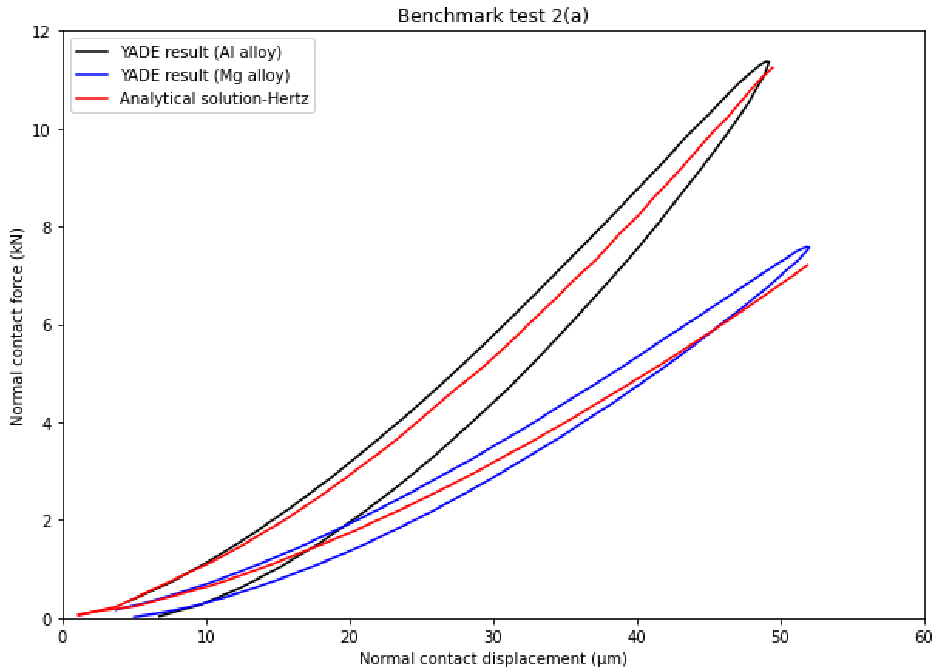


Fig. 1. Test 1: elastic normal impact of two identical spheres: **a.** force-displacement curve; **b.** force-time curve

Conclusions:

a) The analytical solution is the average of the loading and the unloading path which matches with the real-world scenario
b) The YADE simulations are perfectly matching with the PFC3D simulations.

➢ **Test 2**: Elastic normal impact of a sphere with a rigid plane



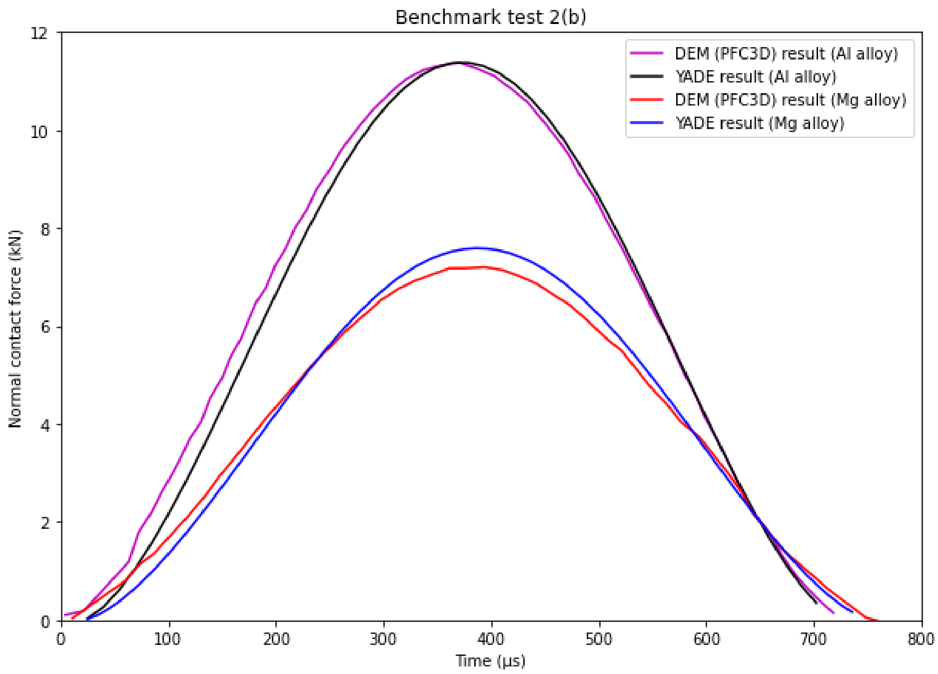


Fig. 2. Test 2: elastic normal impact of a sphere with a rigid plane: **a.** force-displacement curve; **b.** force-time curve

Conclusions:

a) The analytical solution is nearly the average of the loading and the unloading path which matches with the real-world scenario
b) The YADE simulations are nearly matching with the PFC3D simulations.

➢ **Test 3**: Normal contact with different restitution coefficients

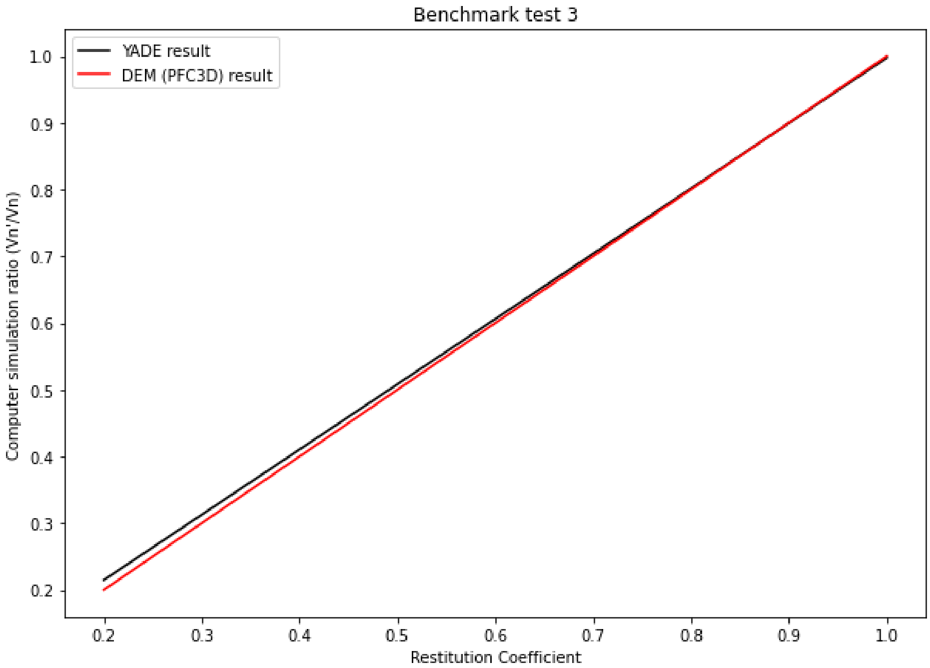


Fig. 3. Test 3: comparison between simulated velocity ratio and input value of the restitution coefficient

Conclusion: The YADE simulation is nearly matching with the PFC3D simulation.

(P.T.O.)

➢ **Test 4**: Oblique impact of a sphere with a rigid plane with a constant resultant velocity but at different incident angles

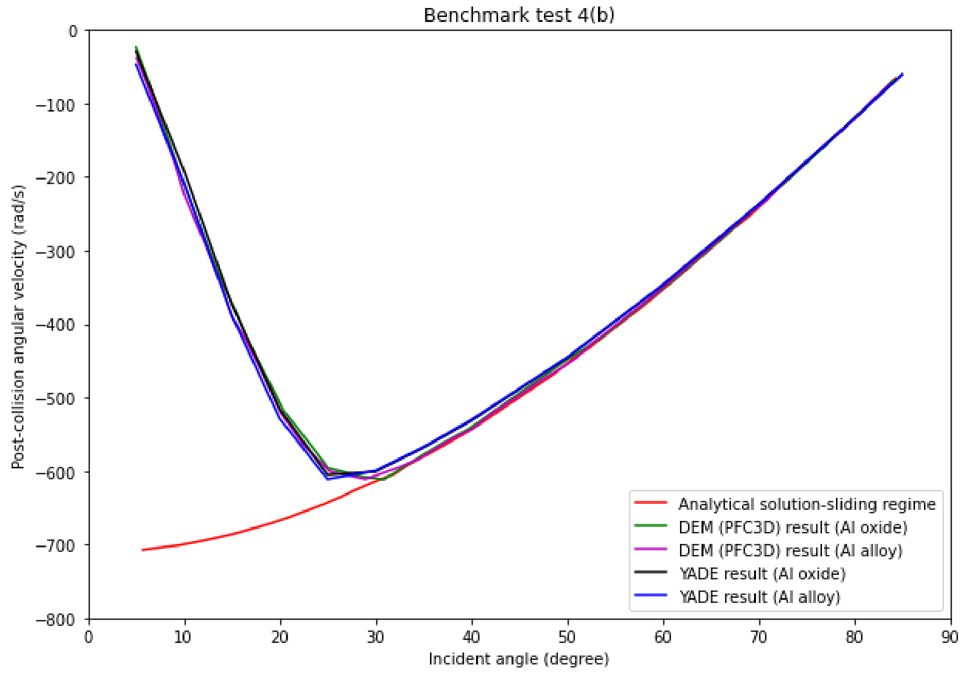


Fig. 4.1. Test 4: simulated, theoretical and experimental post-collision angular velocity ω_1' for varying incident angles θ

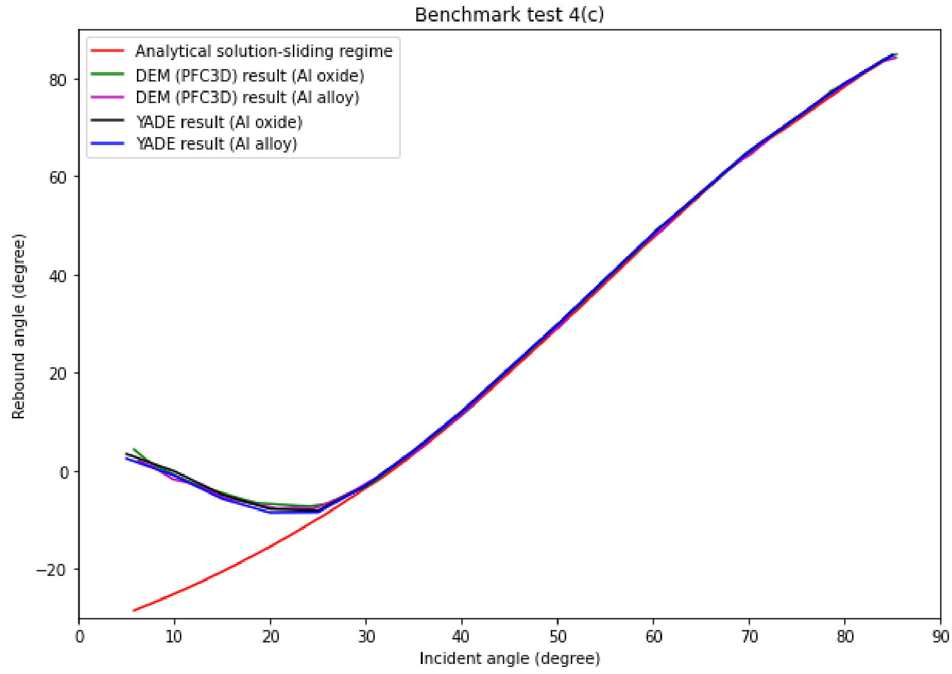


Fig. 4.2. Test 4: simulated, theoretical and experimental rebound angles φ for varying incident angles θ

Conclusions:

a) The YADE simulations are perfectly matching with the PFC3D simulations.
b) The analytical solution is perfectly matching with the DEM simulations for incident angle greater than a critical value $\theta_{critical}$, i.e. in the sliding regime. The discrepancy is found in the stick-regime.

➢ **Test 5**: Oblique impact of a sphere with a rigid plane with a constant normal velocity but at different tangential velocities

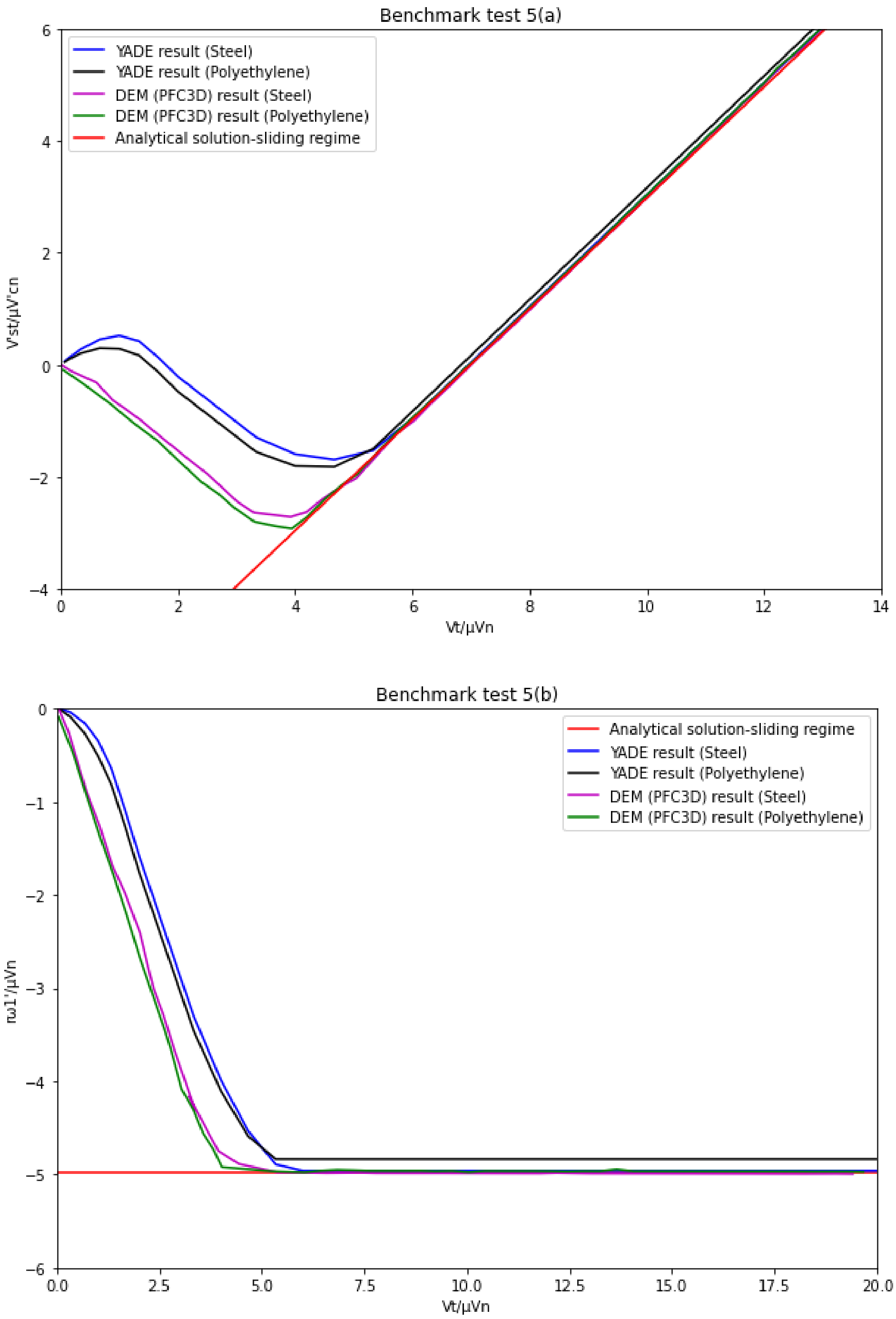


Fig. 5. Test 5: oblique impact for varying tangential velocities: **a.** normalized recoil angle versus normalized incident angle; **b.** normalized post-collision angular velocity versus normalized incident angle

Conclusions:

a) The YADE simulations are perfectly matching with the PFC3D simulations in the sliding-regime. They are not matching in the stick-regime. However, the slopes of the curves are nearly same which indicates that only the critical value of the boundary of stick-slide regime is different.

b) The analytical solution is perfectly matching with the DEM simulations in the sliding regime. The discrepancy is found in the stick-regime.

➢ **Test 6**: Impact of a sphere with a rigid plane with a constant normal velocity but at different angular velocities

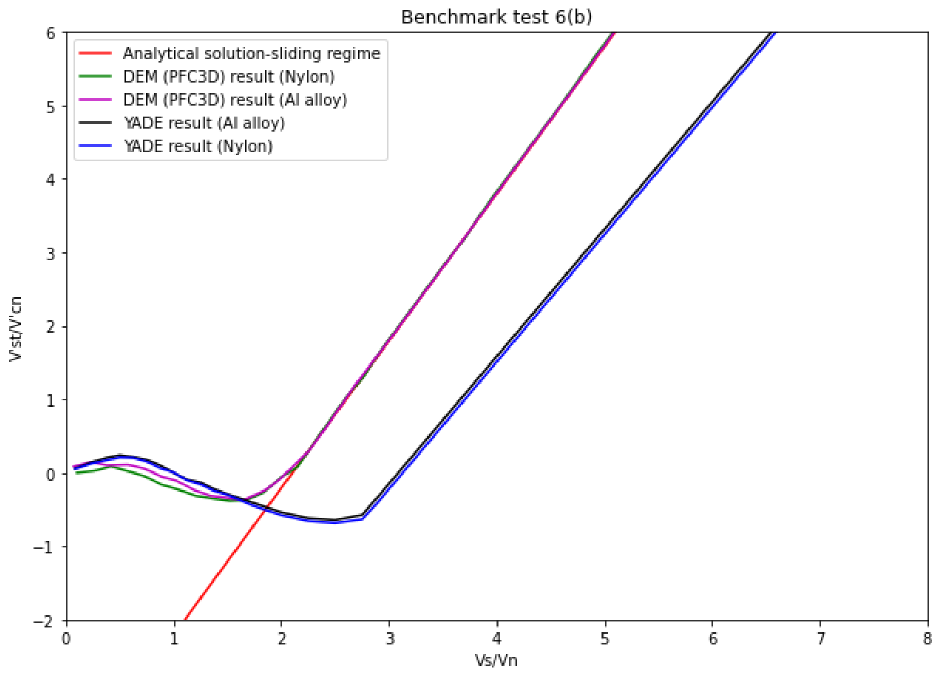


Fig. 6. Test 6: simulated and theoretical tangent of recoil angle $\frac{V'_{st}}{V'_{cn}}$ for varying tangent of incident angles $\frac{V_s}{V_n}$

Conclusions:

a) The YADE simulation is perfectly matching with the PFC3D simulation in the stick-regime. They are not matching in the sliding-regime. However, the slopes of the curves are nearly same which indicates that only the critical value of the boundary of stick-slide regime is different.

b) The analytical solution is perfectly matching with the PFC3D simulations in the sliding regime. The discrepancy is found in the stick-regime.

(P.T.O.)

➢ **Test 7**: Impact of two identical spheres with a constant normal velocity and varying angular velocities

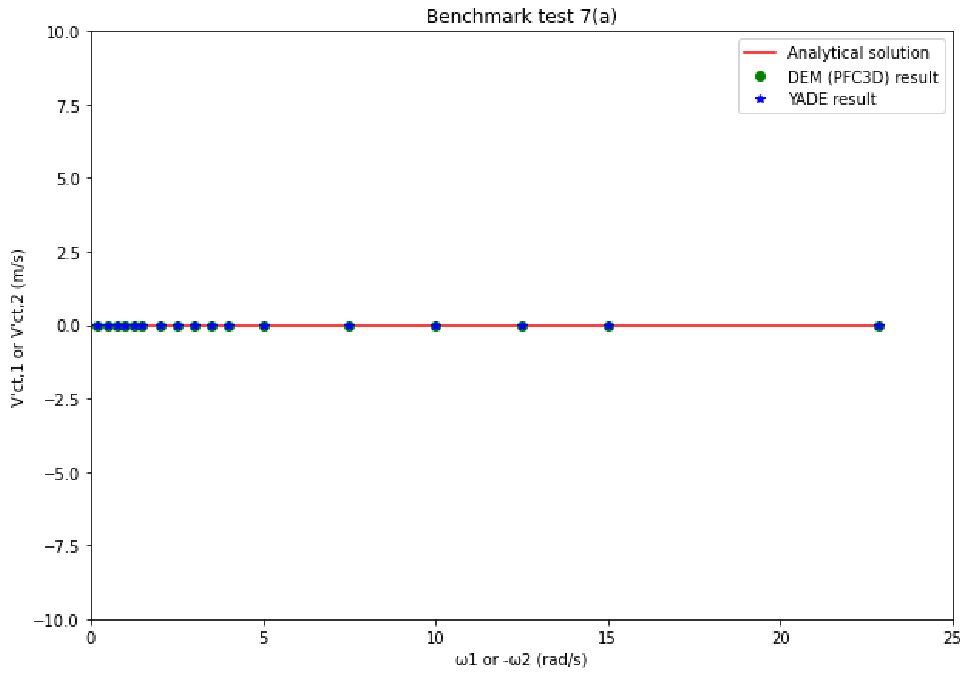


Fig. 7.1. Test 7: post-collision tangential velocity at the mass centre for varying pre-collision angular velocities

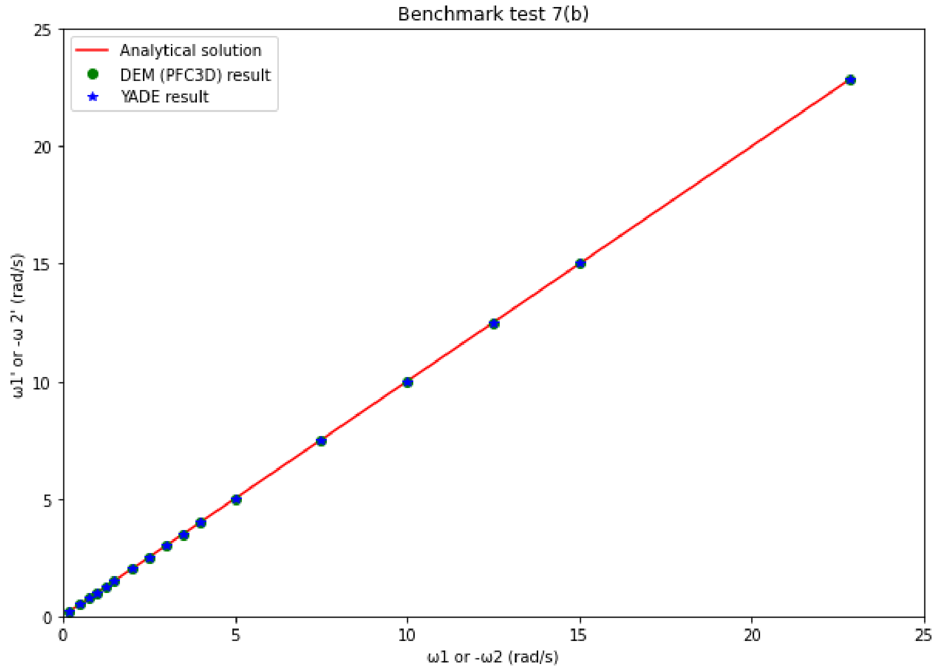


Fig. 7.2. Test 7: post-collision angular velocity for varying pre-collision angular velocities

Conclusion: The DEM simulations are perfectly matching with the analytical solution.

- **Test 8**: Impact of two differently sized spheres with a constant normal velocity and varying angular velocities

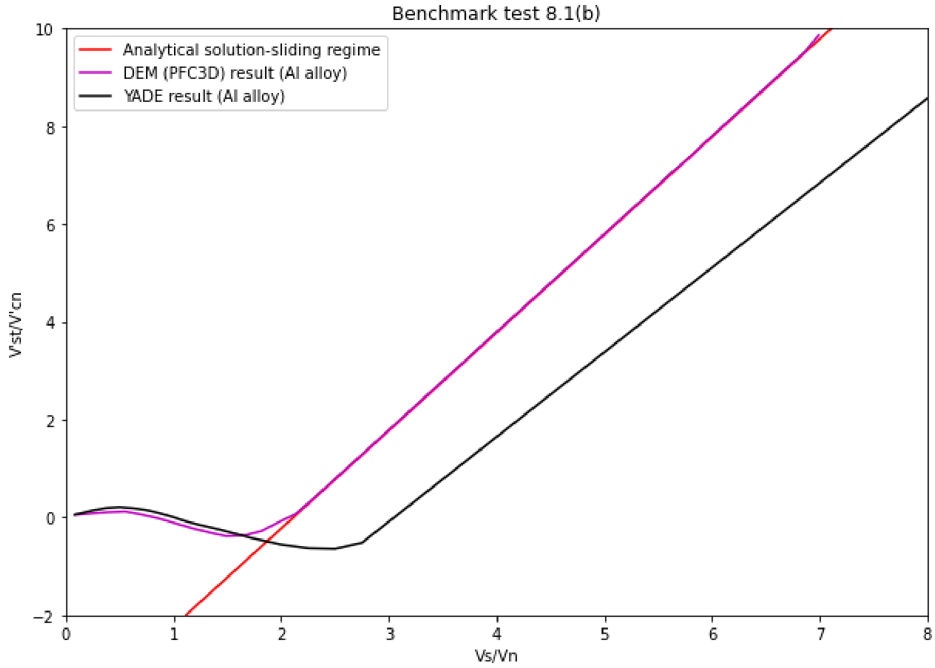


Fig. 8.1. Test 8 (Ex.1. Al. alloy): simulated and theoretical tangent of recoil angle $\frac{V'_{st}}{V'_{cn}}$ versus tangent of incident angles $\frac{V_s}{V_n}$ for the small sphere

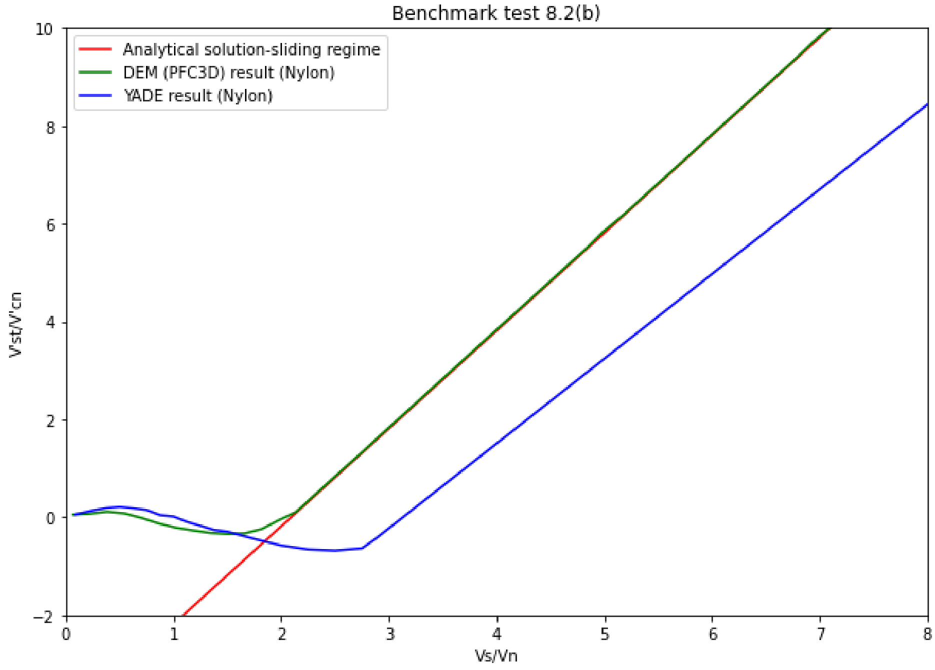


Fig. 8.2. Test 8 (Ex.2. Nylon): simulated and theoretical tangent of recoil angle $\frac{V'_{st}}{V'_{cn}}$ versus tangent of incident angles $\frac{V_s}{V_n}$ for the small sphere

Conclusions:

a) The YADE simulation is perfectly matching with the PFC3D simulation in the stick-regime. They are not matching in the sliding-regime. However, the slopes of the curves are nearly same which indicates that only the critical value of the boundary of stick-slide regime is different.

b) The analytical solution is perfectly matching with the PFC3D simulations in the sliding regime. The discrepancy is found in the stick-regime.