Strain rate profiles and powder compaction testing

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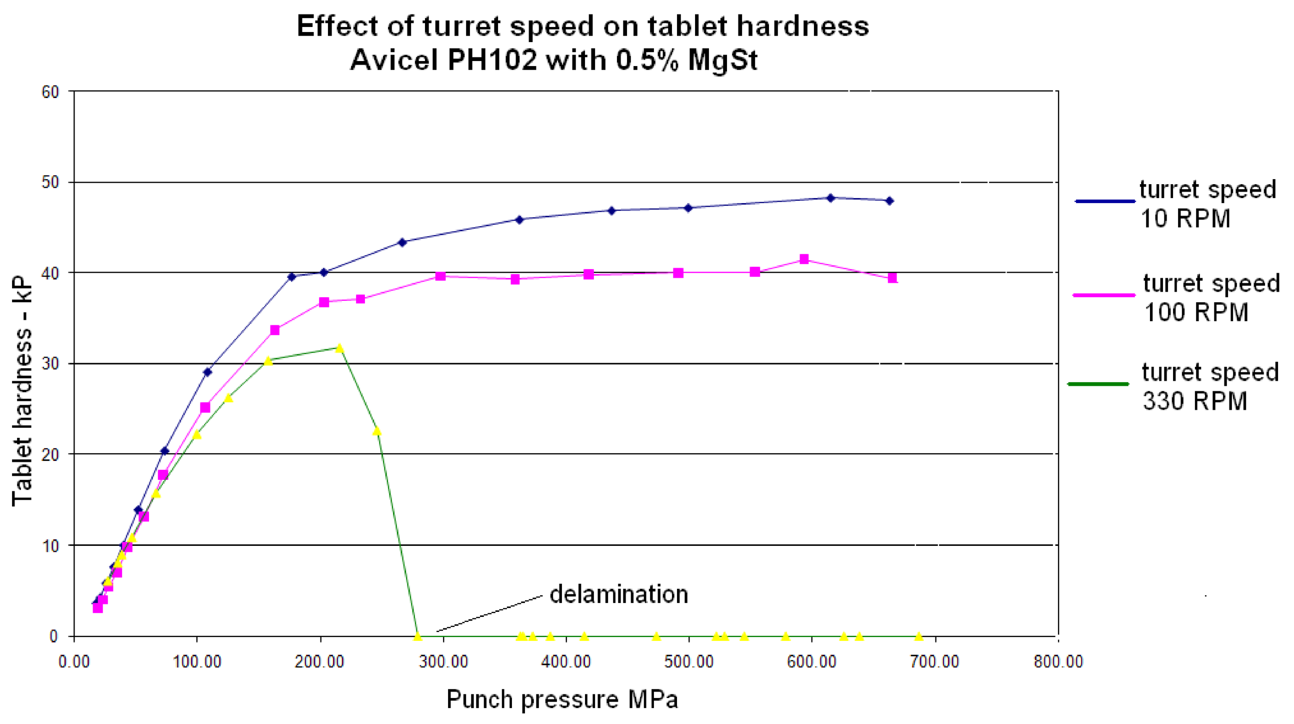
Historically, due to equipment limitations, powder compaction testing has been performed at slow speeds. The wider use of powerful compaction simulators allows more testing to be performed at speeds representative of production, and the strain rate sensitivity of materials is now studied routinely. However, for simplicity, this is often done using constant punch velocity. The actual strain rate, which is then a function of punch separation, varies through the test. This poster presents the differences between constant velocity testing, constant strain rate testing, press simulation testing and constant densification rate testing.

The Huxley Bertram hydraulic Powder Compaction Simulator

Why do Strain Rate Sensitivity testing?

Most materials properties exhibit some strain rate sensitivity, and powder compaction is particularly affected due to the heat generating mechanisms and air entrapment effects. All tablets will fail mechanically at a certain strain rate due to excessive stress gradients or the effects of trapped air, and sensitive compounds may be adversely affected by the heating effects of high strain rates. Avicel is not particularly strain rate sensitive, but the graph below shows strain rate having a marked effect on tablet hardness.

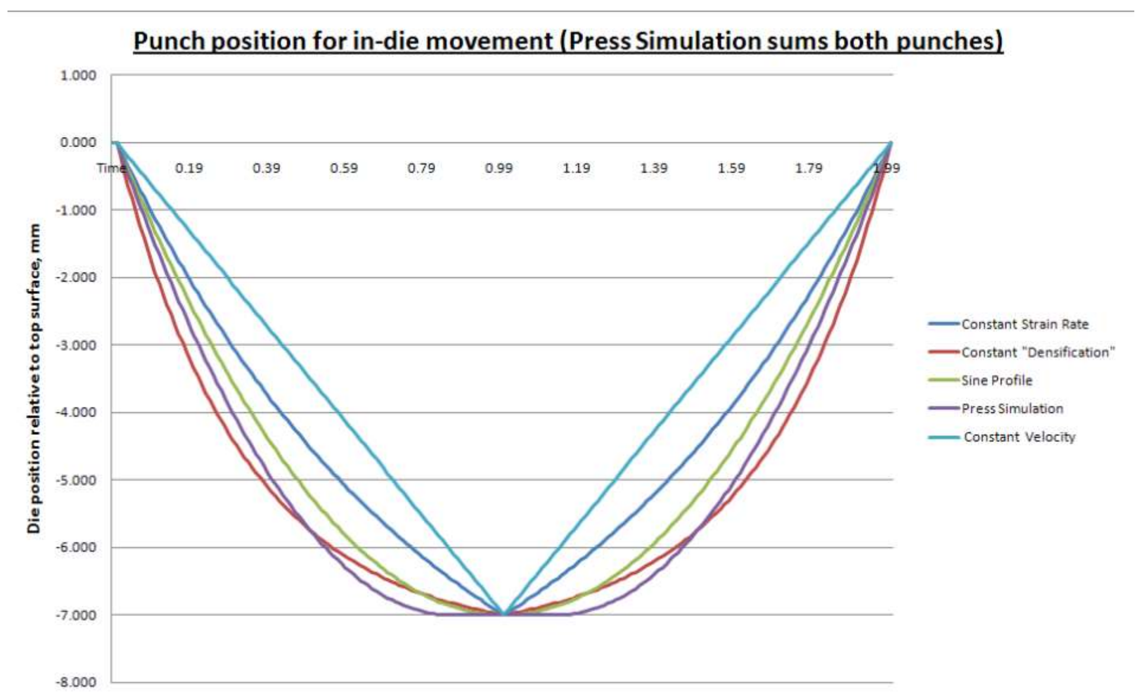


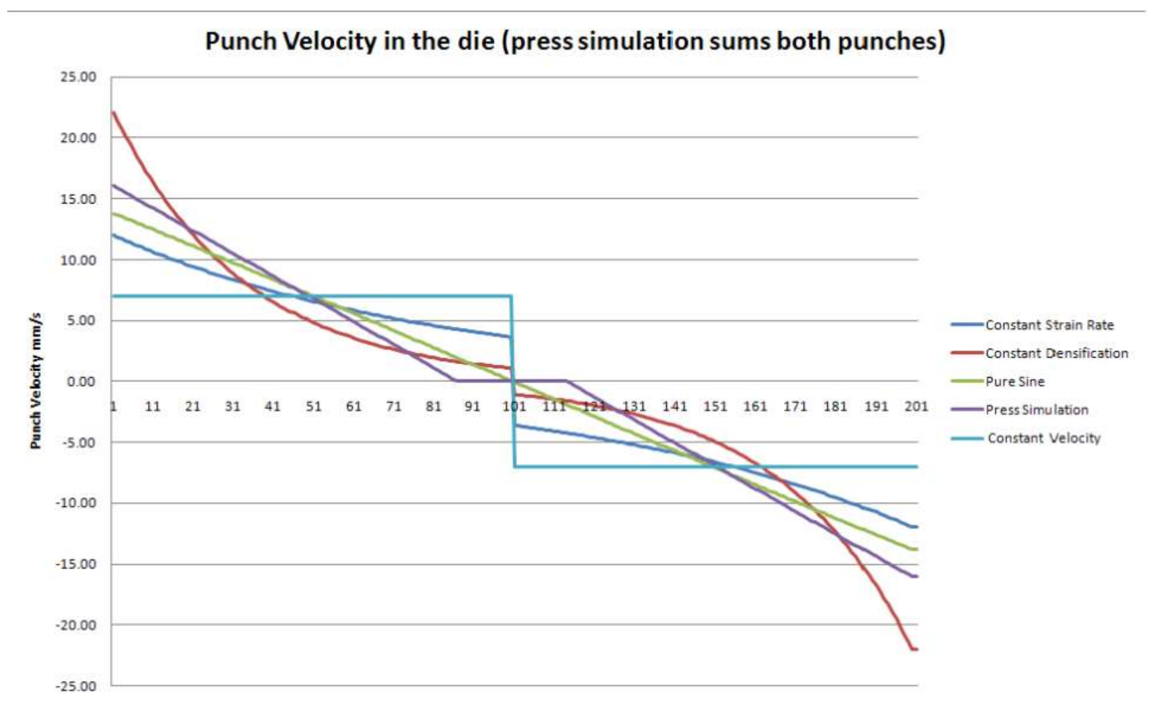
Tradition

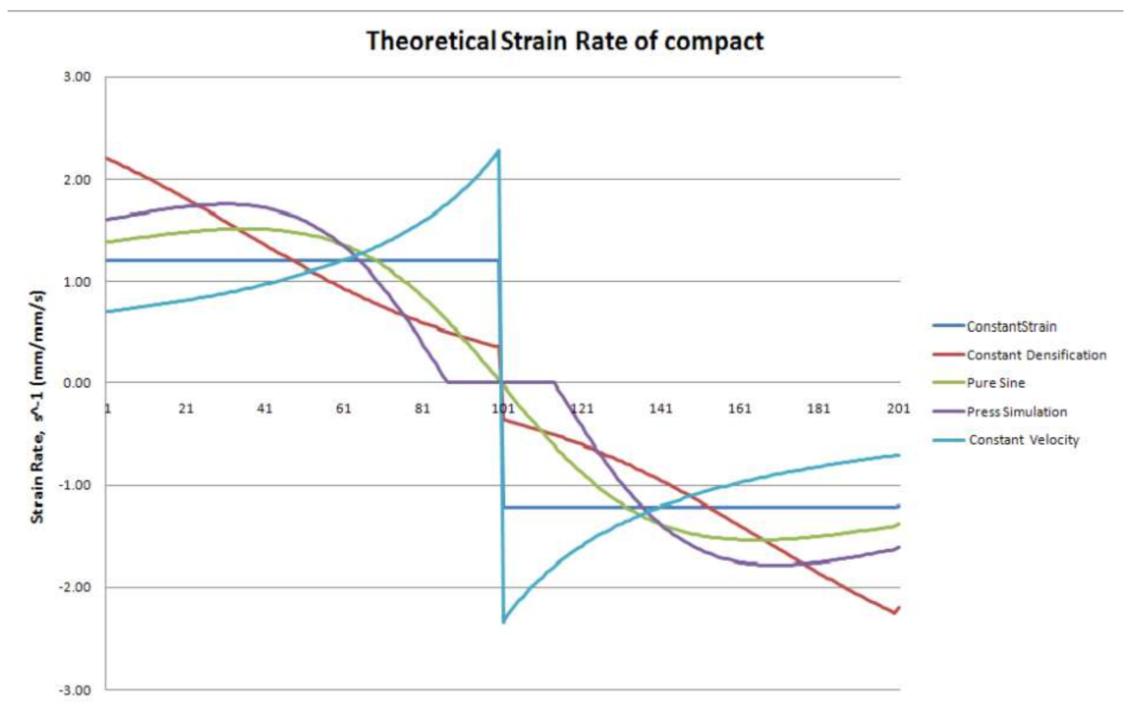
Materials testing standards have traditionally concentrated on metals testing, and compression tests are usually performed on unconstrained metal samples. Strain rate is then simply speed divided by metal thickness, and testing at a constant strain rate makes good sense. However, powders need to be constrained, and then there is an effective limit of compaction, which is the “solid height”. It therefore make sense to consider the solid height as the limit of compaction, and use a constant rate of “densification“.

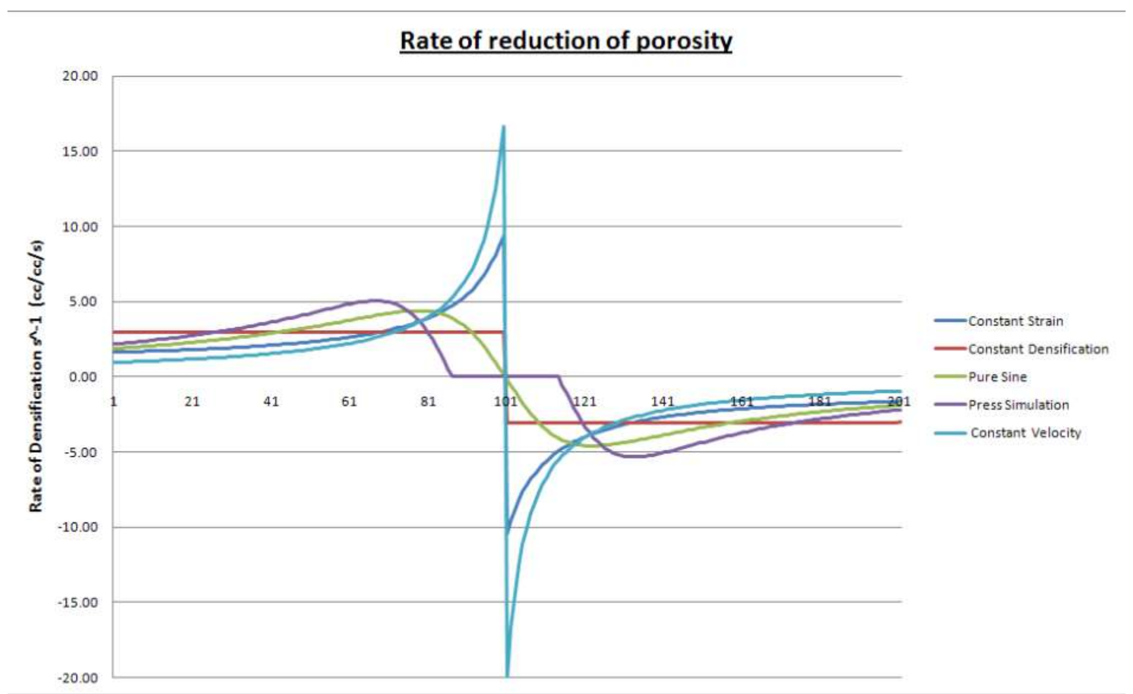
Note this is actually “reduction of porosity” as densification is a factor of the whole volume.

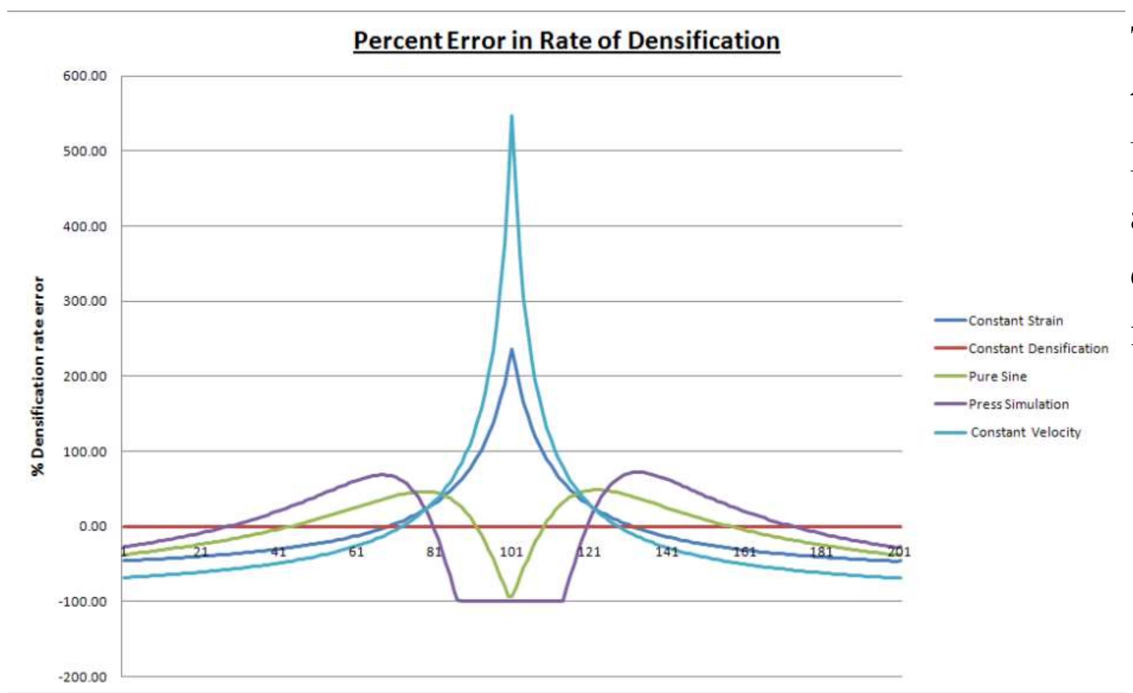
The following graphs show the differences between the various approaches to strain rate sensitivity testing. “V” profiles, Sine profiles, and Constant Strain Rate profiles are typically performed with the lower punch stationary, and the Press Simulation profiles are performed with both punches moving, however both punches can move for any of the tests if required. In the graphs, the press simulation plots are the sum of both upper and lower punch movement. An arbitrary timescale of 2 seconds of travel in the die was chosen to present the results.





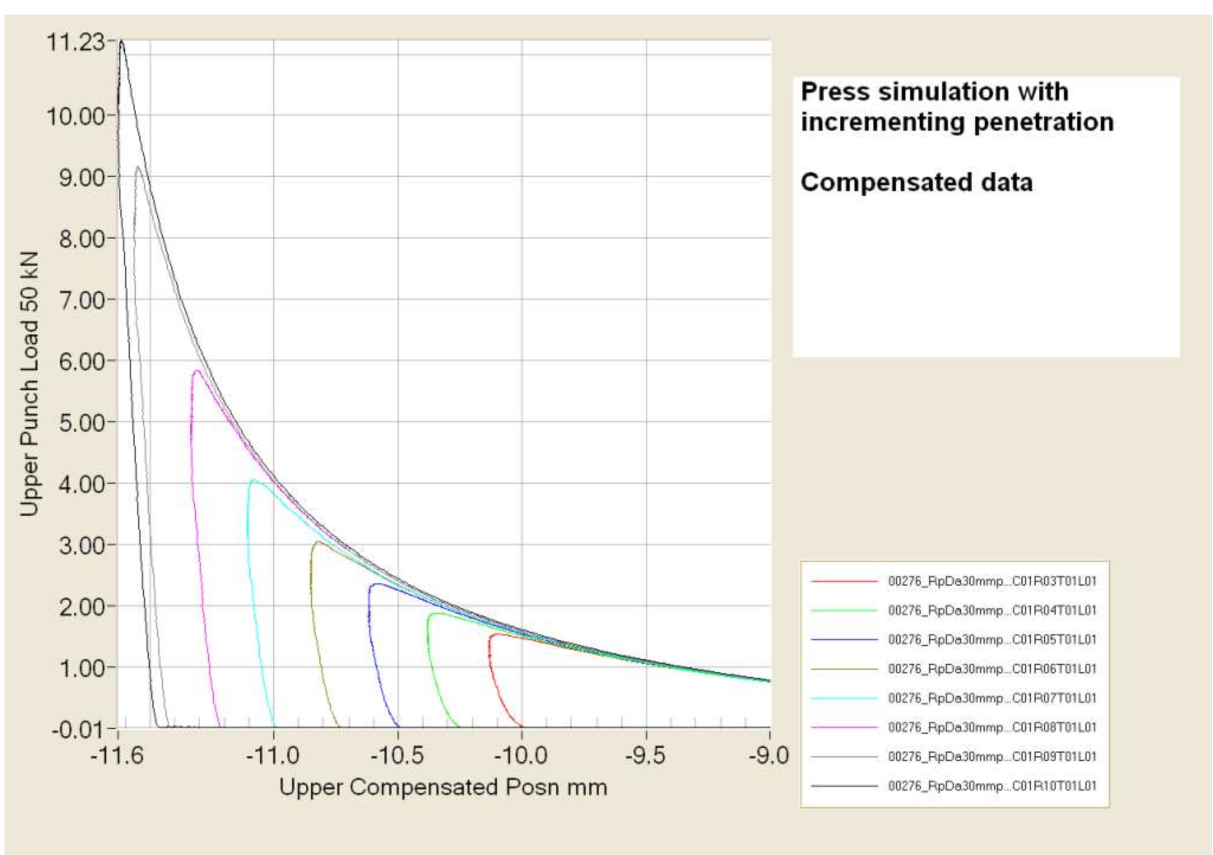


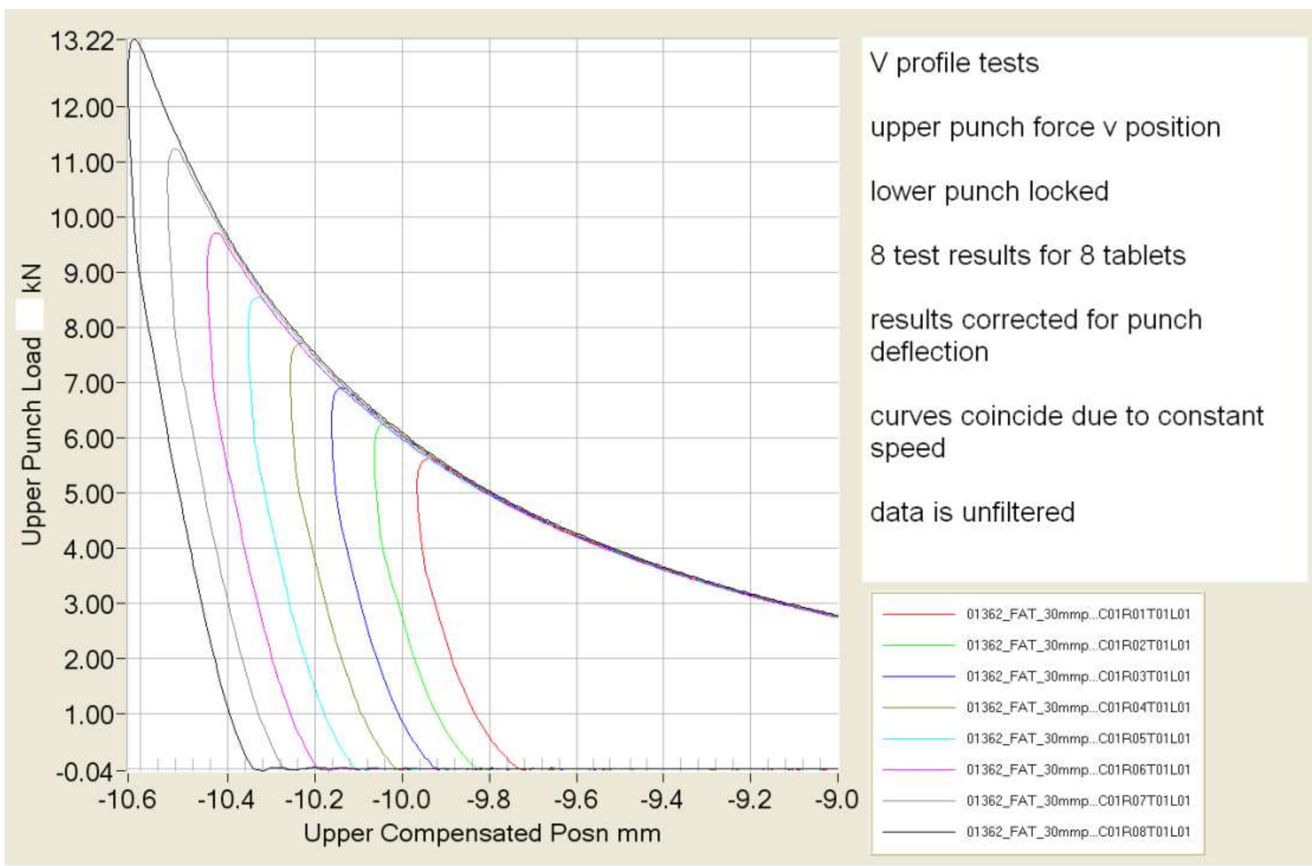




The graphs show that during the critical last 1mm or so of compaction, the different methods give very different compaction rates. Practically, a method is required that is independent of tablet shape, and can be made to work for concave tablets. Constant rate of reduction of porosity (compaction) gives a useful method of achieving this.

The following graphs show the problems of using plain sine or press simulation profiles for materials profiling. These profiles give different strain rates depending on the thickness of the tablet, and then tablet relaxation gives variable results for force and position:. Note that the curves for Press Simulation diverge due to reducing stain rate at the limit of punch travel, whereas the constant velocity tests produce over-laying data.





stress v strain for Avicel PH102 tablets increasing penetration

Practical Considerations:

Controlling strain rates during the final stages of compaction is challenging, and the actual strain rates achieved must be studied. Compliance in the machine and the punches should be compensated in control and in measurement for accurate results.

To achieve strain rate control at production speeds and loads, the compaction simulator must be very strong, accurate and powerful.

Production machines also exhibit compliance and it is useful to know exactly what that is to understand the strain rates that will be applied in practice.

Conclusion:

Strain rate is perhaps the most important tableting variable, and a standard method is needed to measure the strain rate sensitivity of powders. The most sensible method appears to be constant rate of “densification” , i.e. an exponentially decreasing punch separation velocity relative to the porosity of the tablet. Conventional V profile testing gives strain rates that depend on the thickness of the tablet being compacted.