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Predicting dynamic failure of dense granules from static compression tests

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Abstract

This paper shows how static failure loads can be used to predict impact failure of granules. A theoretical model is presented that gives the maximum force experienced during impact and equates this to experimentally measured static failure load to define a critical impact velocity for impact failure. A granule will fail if the predicted theoretical maximum force during impact due to the impact velocity is greater than the real force required to produce failure in that particular granule.

The random nature of granules produces a spread of velocities at which granules of a given size will fail; this spread is the failure distribution. In this paper it is shown that the failure distribution of a series of impact experiments can be represented by a 2-parameter Weibull equation. The important *c*-parameter is related to the impact angle and the critical normal impact velocity that is found from static compression tests. Thus the number of granules failing by impact at each velocity can be found by performing static failure tests.

Keywords: failure; granule; granules; high-shear granulation; compression; static; impact failure; dynamic failure; impact velocity; critical normal impact velocity; Hertzian failure; dense granules; dense granule; static failure; granulation

1. Introduction

Granulation has been an important powder production process in industry for the past few decades. There are many advantages to using granulated material, for example improved flow-ability and improved dissolution characteristics. As granules are so important to so many industries it is desirable to know as much as possible about efficient processing and transportation of granular material. Granules can impact upon each other and process equipment, potentially leading to granule breakage. It would be of useful if we could predict whether granule breakage will occur and, if so, the rate of granule breakage. Granule breakage on impact with a rigid surface depends upon material properties of the granule and the surface as well as the velocity and angle of impact. Despite the long history of research into granulation, it has been difficult to predict granule breakage during processing without using a statistical approach involving extensive impact experiments. This is largely due to the random nature of the number and position of flaws/pores within granules. This leads to a spread of impact velocities required to induce failure within a given sample of granules.

This random spread of failure velocity is indirectly apparent when particles of identical size and material are

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fired at a rigid surface and the number of undamaged granules is counted as shown by Salman et al. (2001) in Fig. 1. In real-life granule processing industries it would be extremely useful to be able to predict the impact failure distribution without the need for extensive impact failure experiments. If the relationship between a granule's material properties, impact velocity and the resulting failure distribution were known then industries could predict the effects that process changes, such as transportation velocity, and material changes have on the amount of granule breakage. The model presented in this paper does just this: predicts the number of undamaged granules after impact from knowledge of impact velocity and angle, granule size and material properties of the granule and impact surface.

It is sensible that for any given granule there is a specific force required to cause the granule to fail by impact loading and a different specific force required to cause the granule to fail under static compression. Further, if a granule's properties are changed such that it becomes stronger and is more resistant to dynamic failure it is intuitive that it should become more resistant to static failure. It is well known that many granules fail by rupture of their interparticle bonds, Subero et al. (1999), and it has long been held that dynamic failure forces are not equal in value to static failure forces. This belief in the inequality between static failure force and dynamic failure force is largely due to the acceptance of creep (permanent deformation caused when certain materials experience low static forces for long periods of time) and high strain rate effects (increased resistance to deformation in some materials when exposed to high forces over very short periods). However it is believed that static failure loads can (in certain cases) be used to represent dynamic failure loads. The model and experimental results presented in this paper support this; as does previous work by Schonert (1979), who compared measured impact strains to evaluated static strains. By conducting static failure tests with relatively high loading rates (increase in force per time) the effects of creep can be ignored. Strain rate effects generally only have significance at high loading rates. It is believed that in this work either; the strain rate is not high enough in the dynamic impact to produce a difference between dynamic failure loads and static failure loads, or the spread in failure distribution as impact velocity increases incorporates the effects of strain rate as well as velocity increase. In either case the assertion that static failure loads can be used to predict dynamic failure distributions holds.

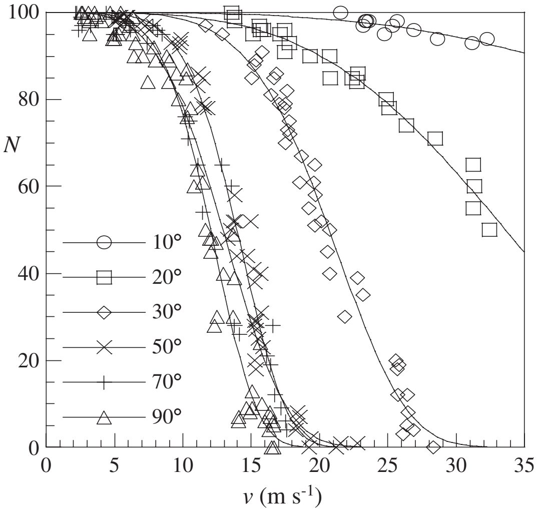

Fig. 1. Undamaged granules, N, as a function of impact velocity and angle.

Thornton et al. (1996) have used numerical solutions to analyse the failure of granules. This is based on simulations of discrete particles within granules and uses models representing the interparticle bonds and the subsequent rupture of these bonds when forces are applied. Another approach, applicable to granules of low porosity and ceramics, is to consider them as brittle elastic material, Galvez et al. (1997). This is the approach adopted in this work, as the porosity of the granules is ≈0.03%. Brittle elastic material allows the use of predicted forces based on the 'Hertzian elastic theory', work originally done by Hertz at the turn of the last century. Granules with porosity greater than those used in the experiments by Salman et al. (2001) will tend to move away from ideal Hertzian Elastic behaviour as the number and size of pores increase. The derivation of the critical normal impact velocity given in this paper should be used with dense granules, and is not applicable to porous granules.

The majority of work on brittle elastic failure assumes spherical particles and deals with elastic failure based on the original Hertzian theory, trying to relate induced stress fields to conventionally measured yield stresses in order to predict failure. Shipway and Hutchings (1993) present a method to find the internal and surface stress fields of a sphere as a function of applied load and contact area. The internal and surface stresses are different functions of the applied load and diameter of the sphere, and thus change at different rates as the load and diameter change.

This paper takes a slightly different approach and uses the predictions by Laugier (1984), dealing with