The remaining five rats have similar but early epithelial growth either at the pylorus or at the antrum. The surviving animals are being observed, in expectation of the eventual occurrence of the tumour with metastasis.

It is interesting that the fore-stomach of all the rats autopsied was quite normal. NG seems to be much more potent in producing tumour in the glandular stomach than 2,7-bis(acetamide) fluorene, 4-nitroquinoline 1-oxide, *N*-nitroso-*N*-methyl urethane or aflatoxin²⁻⁴.

Some of the animals showed adenocarcinoma of the duodenum, myosarcoma of the jejunum or sarcomatous lesions of mesentherium origin. Organs other than the digestive tract were almost unaffected, except in one case which showed liver adenoma.

The mechanism by which NG causes this high incidence of tumorous lesions preferentially in glandular stomach is obscure, and is being investigated. This work was supported in part by a grant from the Ministry of Education.

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APPLIED SCIENCE

Tensile Strength of Granular Materials

RECENTLY Carr¹ and Douglas² have commented on the equation for the tensile strength of granular materials

$$\sigma \simeq \Gamma \frac{Bt}{D^3} \quad (1)$$

as derived by V. Smalley and myself³, where σ is the tensile strength, Γ is a numerical constant, B is the bonding force of particle to particle, t is the thickness of the fracture zone (measured parallel to the stress direction) and D is the diameter of the spherical particles which make up the ideal granular material. As originally formulated³ the constant Γ had a value of 4.6.

Carr¹ suggested a possible modification which could be introduced into Γ , which required selecting the value 8.0, from the results of Bernal and Mason⁴, to be the co-ordination number of the spheres in the random aggregate rather than using the mean value of 8.5. Bernal and Mason distinguished two types of contact in their random sphere packing, close and near. In a liquid bonded system in the pendular state, bonds should exist at both of these types of contact, so the co-ordination number which should be applied is the one for mean total contacts in a close random pack of spheres, that is, 8.5. If the dry case is being considered it might be justifiable to consider just the close contacts, in which case the co-ordination number would be 6.4. In neither case is the 8.0 value strictly applicable.

B. B. Morgan, of the British Coal Utilisation Research Association, in a private communication, however, had previously pointed out two necessary modifications in the method which do change the value of Γ . In particular, in considering the number of bonding forces in the system it is more convenient to consider that one bond unit

exists for every two contact points on individual spheres rather than consider that every contact point represents a bond unit. This revision alone introduces a factor of two into the original formulation. The other anomaly indicated by Morgan was the unjustified appearance of the $\sin \theta$ term in equation (7) (in ref. 3) and its resulting disturbance; also a B has been omitted from equation (10) (in ref. 3). If the Morgan modifications are applied, the tensile strength equation becomes

$$\sigma \simeq 2.8 \frac{Bt}{D^3} \quad (2)$$

The numerical constant changes but most of the equation does not; the dependence of the tensile strength on D^3 remains. In other words, the number of bonds in the fracture zone depends on a volumetric control. For this to be valid, the model requires that the fracture section should be considered as having a finite thickness t and thus a real volume. Fracture takes place in the section in a manner somewhat similar to that described by Orr⁵: when an agglomerate of spheres is pulled into two pieces, the spheres must go with one or other of the two parts. If those in the fracture zone choose to remain with the part in which they are most deeply buried, the effective fracture region about these spheres can be as much as 0.5 the area of a sphere and as little as zero. The fracture scheme described by Douglas² in which the particles come apart without themselves contributing to the strength is not applicable.

As Carr pointed out, the original equation of V. Smalley and myself is dimensionally consistent, and is also a valid representation of a specific model fracturing system in which t cannot be directly related to D . If t can be expressed in terms of D , then a dimensionally consistent expression of the form evolved by Rumpf⁶ is possible

$$\sigma \simeq 2 \frac{B}{D^2} \quad (3)$$

But there seems to be a paradox here, because to fit in with the dimensional requirement t must apparently increase with D , but in the original Rumpf formulation t was not only constant, it was actually zero in all cases. The three dimensional section of thickness, t , is more satisfactory. It still, despite Carr's objection, provides an intuitive indication that the strength of an ideal granular material is inversely proportional to the volume of the particles. If the fracture zone is three dimensional it can be thought of as a container, say a tobacco tin. The number of contacts depending on the number of spheres which can be placed in the tin and this depending on the size (volume) of the particles and thus on D^3 . In the original derivation of V. Smalley and myself, the inter-particle force B was assumed to be independent of particle size and this is still a necessary condition.

Equation (6) of Douglas² is in agreement with the corresponding equations by Rumpf⁶ and V. Smalley and myself³ in that the tensile strength was found to be directly proportional to B and this seems reasonable for real granular materials. The major problem still remains, as Morgan⁷ showed so clearly for dry particulates, to relate D to σ for real materials.

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