**PHYSICAL AND MECHANICAL PROPERTIES OF COMETARY NUCLEI.** E. N. Slyuta, Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow. E-mail: slyuta@mail.ru.

**Introduction:** The fact of tidal destruction of a cometary nucleus suggests that the nucleus consists from fragile and weak enough material and on the physical and mechanical properties considerably differs from a usual solid body. Progressive cometary meteor fragmentation caused by aerodynamic pressure in the Earth's upper atmosphere is also diagnostic of general fragility and porosity of cometary meteoroids. From the point of view of physical and mechanical properties, all known cometary nuclei models can be subdivided into two basic classes. These are; "fractal" and "rubble pile" models. Material strength of a "fractal" model depends on intergrain cohesion forces which are dependent on the chemical and mineralogical structure of a cometary nucleus. "Rubble pile" model consists of particles or separate fragments which are not connected among themselves and are kept together only by self-gravitation and bodies with a rather small mass are considered as strengthless [1, 2].

**Mechanical properties:** Analytical, observed and experimental data on strength properties of cometary material and its analogues are submitted in Table 1. These data show that tensile strength of cometary material is distinct enough from strengthless material. Theoretically most proved the value of tensile strength corresponds to a range of $0.081\times10^4$ - $3.6\times10^4$ din cm$^{-2}$ [2]. It is necessary to note, that extreme values of this range correspond to extreme and, accordingly, to improbable values of porosity and density. The observable data described by the least uncertainty and the least disorder, are received mainly at destructions cometary meteoroids by aerodynamic pressure in the Earth's upper atmosphere. The summary analysis which has been carried out by McKinley [3] according to supervision for many years, has shown, that practically in all observable meteoric streams which source are comets, cometary meteoroids has been disintegrated at aerodynamic pressure of $2\times10^4$ din cm$^{-2}$. This value corresponds approximately to average and conservative value of tensile strength, satisfying to almost all considered data which have been received by different methods and with a different degree of uncertainty.

**Technique:** Mechanical and rheological properties of material exert influence on parameters of the gravitational deformation caused by a nonequilibrium figure and mass of small bodies [4-6]. An analysis of mechanical properties of cometary nuclei has been carried out with a rheological model, which uses the elastic theory with ultimate strength for a three-dimensional self-gravity body, and allows the exact solution of differential stresses in a solid elastic body to be received and to carry out their analysis [5].

**Cometary nuclei's effective tensile strength:** Using a stress deviator equation (Eq. 10 [5]) for 19P/Borrelly comet [7], 67P/Churyumov-Gerasimenko comet [8], 81P/Wild 2 comet [9], 9P/Tempel 1 comet [10] and Halley comet [11] (Table 2) we can estimate the stress deviator caused by shape parameters and mass of their nuclei. We take a Poisson coefficient of 0.31 [12]. The stress deviators obtained are small and are of two orders of magnitude lower than the cometary material tensile strength (Table 2).

**Table 2**. Cometary nucleus stress deviator*

| Comet | Semiaxes ($a\times c$), km | Density, g cm$^{-3}$ | Stress deviator, $\times10^2$ dyn cm$^{-2}$ |
|---|---|---|---|
| Borrelly | 4×1.6 | 0.3 | 2.2 |
| Churyumov–Gerasimenko | 2.43×1.85 | 0.5 | 2.5 |
| Halley | 8×4 | 0.28 | 3.4 |
| Tempel 1 | 3.8×2.45 | 0.6 | 6.0 |
| Wild 2 | 2.75×1.65 | 0.6 | 3.3 |

*- References are in the text.

Taking a cometary nucleus density equal to a conservative value of 300 kg m$^{-3}$ [2] and a Poisson coefficient of 0.31 [12], and using a stress deviator equation (Eq. 10 [5]), we obtain a cometary nucleus size of 54 km, at which the stress deviator is equal to the cometary material tensile strength ($2\times10^4$ dyn cm$^{-2}$). That is the size of the largest comet Hale-Bopp within its size estimation uncertainty [13]. This means, that cometary nuclei less than 54 km in size (which is the case practically all of the known comets) have a constant tensile strength of about $2\times10^4$ dyn cm$^{-2}$, which is determined by structure only. At achievement of tensile strength as a result of tidal destruction, collision, or ram pressure at sublimation, bodies of less than 54 km in diameter irrespective of their mass would be split easily enough, increasing a population of ones. Effective tensile strength of the bodies more than 54 km in size is determined by a body mass and shape parameters and increases under the square-law depending on a body size and mass [5] (Fig. 1).

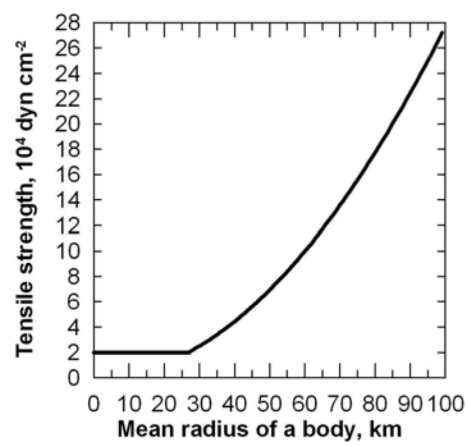


**Fig. 1.** Dependence of effective tensile strength on size of a cometary nucleus.

Such increase of the tensile strength can explain a deficiency of cometary nuclei more than 54 km in size (size gap). In total there are about 700 known comets. All of them have nucleus diameter less than ~60 km except for 2060 Chiron which has diameter about 200 km [14]. Comets with a radius between ~60 km to 200 km have not been presently found. At least, effective tensile strength increasing should influence number of a secondary population, which is formed as a result of the destruction of parent bodies.

**Table 1**. Tensile and compressive strength of cometary material

| Tensile strength, dyn cm$^{-2}$ | Compressive strength, dyn cm$^{-2}$ | Object | Technique | References |
|---|---|---|---|---|
| Strengthless | | P/Shoemaker-Levy 9 | Tidal breakup model | [1] |
| $10^3$-$10^5$ | | Sungrazing comets | Tidal breakup model | [15] |
| $<10^3$ | | Model | Tidal breakup model | [16] |
| $>10^4$ | | P/Giacobini-Zinner | Rotational breakup mode | [17] |
| $<10^5$ | | Sungrazing comets | Ram pressure | [18] |
| $2.5\times10^4$ | | Draconids meteor stream | Aerodynamic pressure | [19] |
| $0.74\times10^4$ | | Draconids meteor stream | Aerodynamic pressure | [20] |
| $1.35\times10^4$ | | Leonids meteor stream | Aerodynamic pressure | [20] |
| $1.4\times10^4$-$1.9\times10^5$ | | Draconid fireball PN39043 | Aerodynamic pressure | [17] |
| $2\times10^4$ | | Meteor streams | Aerodynamic pressure | [3] |
| $2.7\times10^3$ | | P/Shoemaker-Levy 9 | Aggregated dust model | [21] |
| $8.1\times10^2$-$3.6\times10^4$ | | Model | Aggregated dust model | [2] |
| $10^5$-$10^6$ | | Cohesive dust matrix | Aggregated dust model | [22] |
| $\sim10^4$ | | Dust matrix, regolith | Aggregated dust model | [22] |
| $\sim10^4$ | | Ice/matrix debris mixture | Aggregated dust model | [22] |
| | **(**$3.9\times10^5$-$2.45\times10^6$**)** | $SiO_2$ dust matrix | Experimental data | [23] |

When self-gravity dominates tensile strength (i.e. small bodies of >54 km in size), fracture starts at the surface and the object erodes inward, while in small bodies in which self-gravity do not dominate tensile strength (i.e. small bodies of <54 km in size) fracture begins in the center [1]. Irrespective of the 3D smooth particle hydrodynamics (SPH) code model [1] the similar character of destructions is one of the strong conclusions of the rheologic model [5] and it depends not only on mass, but on shape parameters also. Though a radial gradient of the stress deviator is insignificant, but it is present [5], and at shape parameters of *a/c* <1.75 the stress deviator on the body surface is more than in the center (Fig. 2).

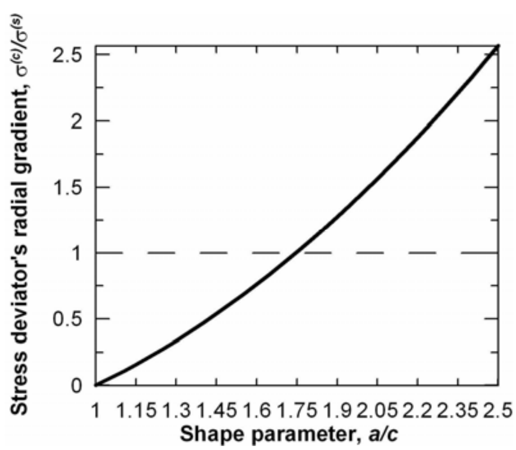


**Fig. 2.** Dependence of a radial gradient of the stress deviator on shape parameters. $\sigma^{(c)}$ - stress deviator in the center; $\sigma^{(s)}$ - stress deviator on the surface; *a*>*c* - semi axes.

Hence, any elastic or plastic deformation will develop from a surface to the center of a body. With the value of shape parameters at *a/c*>1.75 the mark of a radial gradient of the stress deviator varies up to opposite (i.e. it does not decrease, and increases with depth) and the mechanism of destruction of a body will be the same, as well as for bodies of <54 km in size. As a result of collisional history or tidal splitting of Kuiper objects of >54 km in size such dependence on shape parameters may result in gradual degradation of bodies's population with shape parameters of *a/c*> 1.75, and as consequence, to their observable deficiency in relation to the bodies with shape parameters of *a/c* <1.75.

**Summary:** Effective tensile strength of the bodies of >54 km in size is determined by body mass and shape parameters and increases under the square-law depending on body size and mass. Such increase of the effective tensile strength may explain a lack of cometary nuclei of >54 km in size (size gap). Dependence of destruction on shape parameters for Kuiper objects of >54 km in size may result in deficiency of bodies's population with shape parameters of *a/c*> 1.75, in relation to bodies with shape parameters of *a/c* <1.75. For cometary nuclei and Kuiper objects of <54 km in size this selection will not operate, as their effective tensile strength is determined by structure only and does not depend on a body mass.

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