Cold Strength and Hot Disputes

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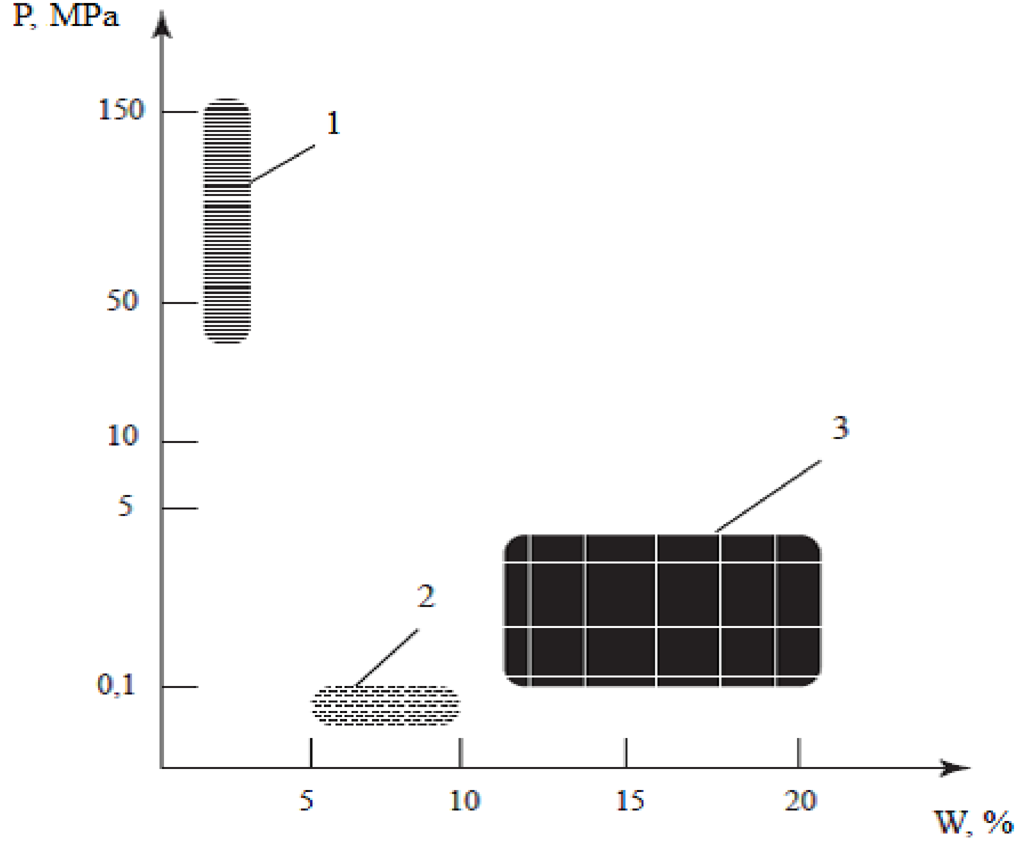
The Main Methods of Modern Briquetting

- For the briquetting of dry materials with organic binders, when the achievement of high hot strength of briquettes is not required, **roller-press briquetting** allows to obtain mechanically strong briquettes due to the application of high pressure (**up to 150 MPa**).
- **Vibropressing** allows agglomeration of a mixture containing a substantial part of large fractions (**up to 10 mm and more**) but requires special measures to preserve the mechanical strength of raw briquettes (moving on pallets, heat and moisture treatment) and does not allow moisture of the briquetted mixture to exceed **12-15%**.
- **Stiff extrusion** allows to agglomerate mixtures with a moisture content of up to **20%** at compacting pressures an order of magnitude lower than in a roller press (**3.5 MPa**).

The Main Methods of Modern Briquetting



1- Roller-pressing; 2- vibropressing; 3-stiff extrusion

Mechanical Strength of a Briquette

- The mechanical strength of the briquette shows how it resists the applied mechanical forces, which tend to deform or destroy it.
- The strength of the briquette is one of its most important metallurgical properties.
- It depends on the type of applied load (magnitude and dynamics, method of application), the shape and texture of the surface, type of binder, etc.
- Strength can be measured in kgF/sq.cm, kg/sample and in % of mass content of fines after testing.
- The main types of briquette strength are:
  - impact strength (height differences, loading into the hopper, shipping, unloading)
  - resistance to compression (in bunkers and in stacks, in railroad cars);
  - resistance to abrasion (railroad cars, shaft furnaces, conveyors for filling and unloading storage bins).

Methods for measuring briquette strength

- To date, there are practically no generally accepted specialized methods for determining the mechanical strength of briquettes.
- Only the methodology for testing the mechanical strength of coal fuel briquettes (GOST 21289-75), adopted in the USSR, is known. It included a compression test on a hydraulic press, dropping from 1.5 meters and a drum sample of 10 kg of briquettes (rotation for 4 minutes, 100 full revolutions)
- In the absence of specialized methods for testing briquettes for strength, the methods adopted for such tests of coke, sinter and pellets are used in practice.
- The rejection limits adopted for such materials are automatically transferred to a fundamentally different class of cold-agglomerated material and this is a topic of ongoing hot disputes.

Methods for measuring briquette strength

- Drop strength
- Compressive strength
- Tumble testing

Drop Strength Testing

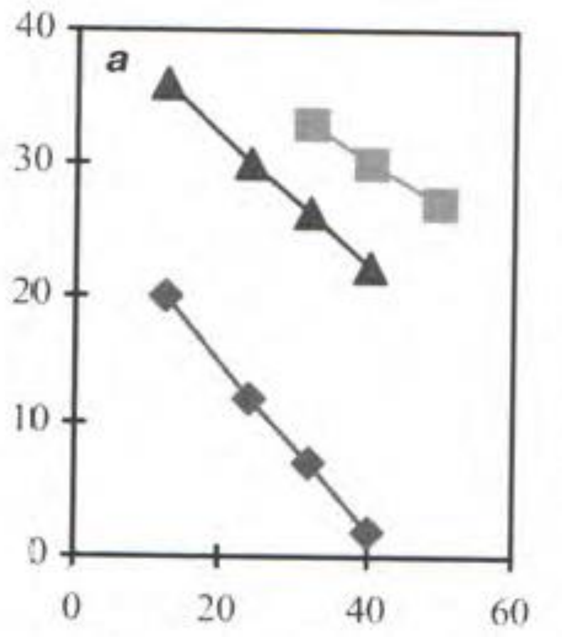
- Depends on the type of binder used;
- Depends on the volume (or mass) of the briquette;
- Destruction is due to a critical number of structure inhomogeneities, which increases with increasing sample size. Even for the same material with the same concentration of structural defects, the probability of destruction increases exponentially with increasing volume.
- Two groups of dropping tests are distinguished
  - dropping a batch of briquette samples
  - sequential dropping of a single briquette sample

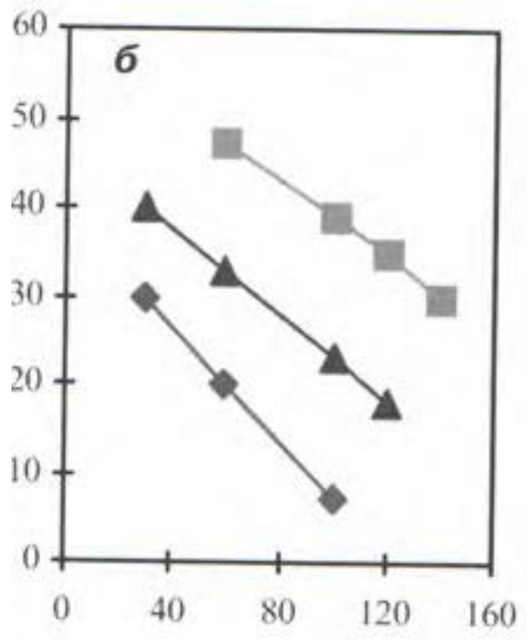
Drop Strength Testing

- Dropping a batch of briquette samples:
  - Batch 1-4 kg; height 1.5-2.0 m; fines yield 5, 10- or 25-mm fractions;
  - Large briquettes (+100mm) 1-2 times; 25-30 mm 4-5 times.
  - It is believed that the quality of the briquettes is satisfactory if not more than 5, 10 or even 15% of the fines are formed.
- Sequential dropping of a single briquette sample:
  - from a sample of 2-4 kg, each single briquette (at least 10-15 pieces) is dumped from a height of 0.5 meters, 1 meter or 1.5 meters.
  - the number of falls that the briquette can withstand until complete destruction is considered an indicator of its strength.
  - briquette strength is considered high if it can withstand more than 10 drops from 1.5 meters and satisfactory if it can withstand more than 10 drops from 0.5 meters, at least 6-7 drops from 1 meter or 4-5 drops from 1.5 meters.

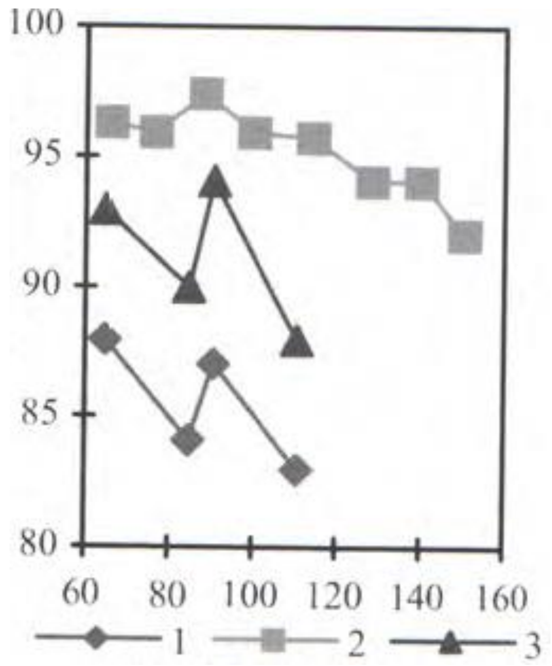
Drop Strength Testing

single briquette sample sequential dropping





dropping a batch of briquette samples



Briquette volume, cub.cm

Briquette mass, g

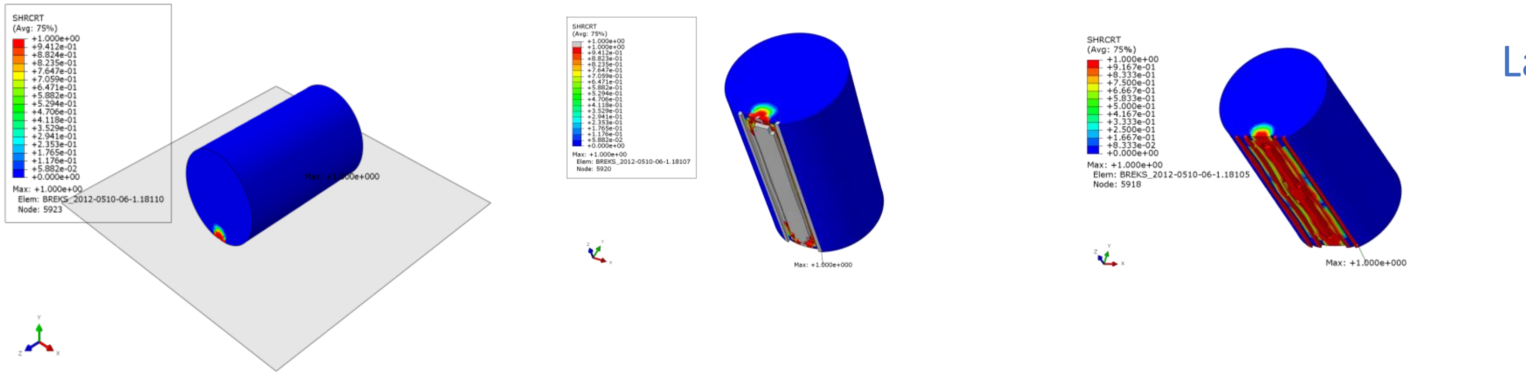
Briquette mass, g

chromite concentrate and liquid glass

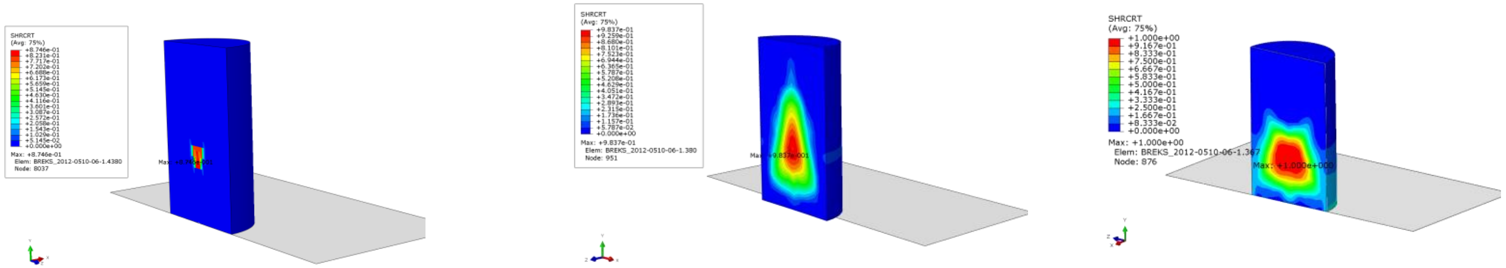
ferrosilicon and oil pitch

copper concentrate and sulphite-alcohol bard

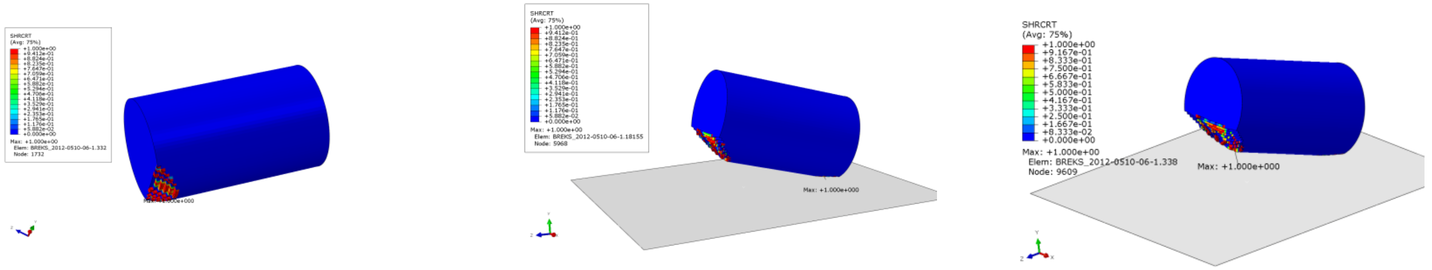
The Distribution of Damage in a Cylindrical-Shaped Briquette



Lateral surface: 0.5m; 1.5m; 2.0m

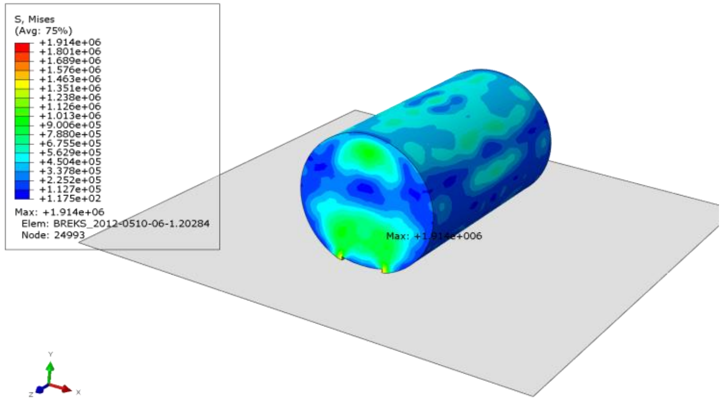


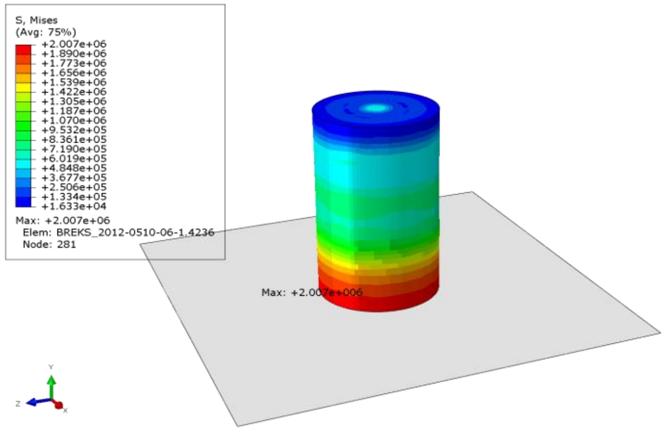
Front surface: 0.5m; 1.5m; 2.0m

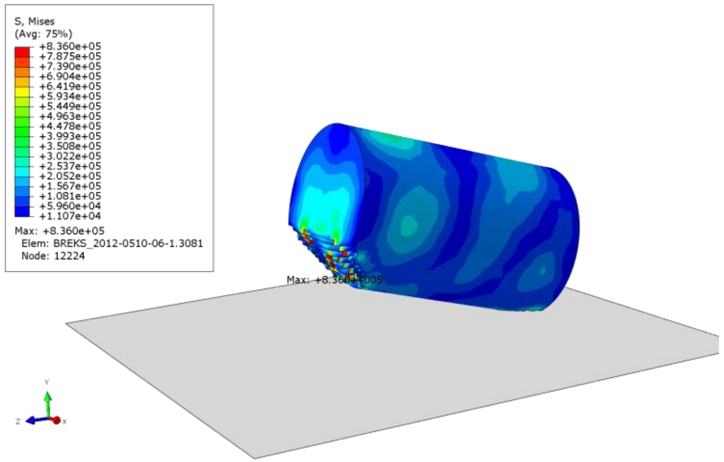


Edge: 0.5m; 1.5m; 2.0m

The Distribution of Stress in a Cylindrical-Shaped Briquette







Lateral surface 1.5 m

front 1.5 m

Edge 1.5 m

Drop Strength. Bentonite

Drop Strength Testing

- Thus, it is seen that dropping strength is determined by several factors and significantly depends on the type of briquetted material and binder, on the method of organization of the test fall.
- This obviously requires the establishment of a differentiated rejection limit for such tests of briquettes of various nature, mass and volume. Otherwise, confusion and conflict may arise in assessing the suitability of the briquette.
- The manifestation of impact strength is required only at the stage of briquette delivery to the metallurgical unit or, in the case of commodity briquettes, to the final remote consumer. To achieve the necessary hot strength in a shaft furnace, a noticeably smaller amount of binder is required than to overcome multiple drops from a height.
- It is necessary to bring the drop test in line with the actual logistics for the delivery and acceptance of agglomerated raw materials and, if possible, create a new logistic trajectory for such delivery with the minimum possible amount of drop from a great height.

Compressive Strength

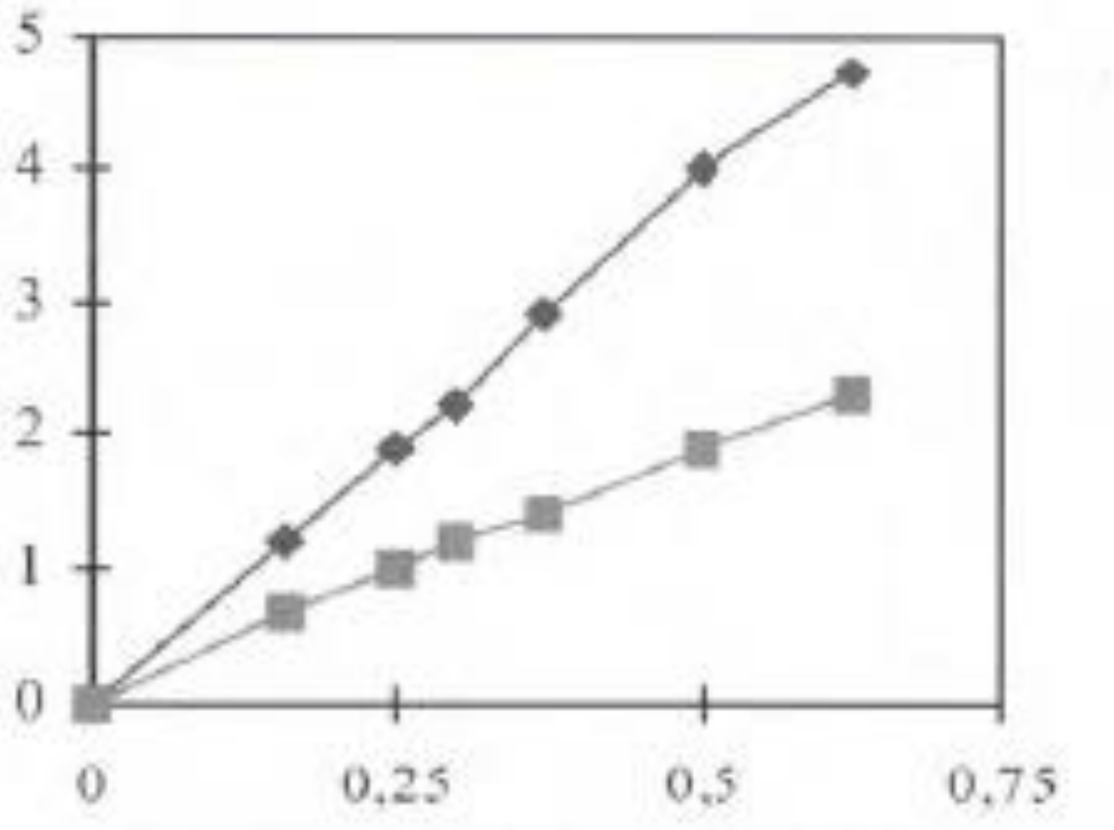
- In case of difficulty in choosing the rejection limits for the strength of briquettes by dropping, as a rule, indicators of their compressive strength are used. However there is no unambiguous a priori correlation between drop strength and compressive strength.
- The brick can withstand considerable compressive forces but is easily destroyed after 2-3 falls from 1.5-2 meters.
- The values of compressive strength depend on the pressing forces and the type of binder.
  - briquettes on bentonite and bituminous binders withstand significant shock loads, but with relatively low compressive forces, they deform and crumple.
  - liquid glass briquettes having a high resistance to compression, are prone to cracking when dropped.

Compressive Strength

- For fluxed pellets, compressive strength is 1.5-2 kN per pellet. For non-fluxed ones - 1.8-2.5 kN per pellet. Based on this some ‘specialists’ draw the wrongful conclusion that the compressive strength of the briquette must be at least 250 kgF/cm^2.
    - in the bunker, the pressure of the vertical layer of pellets (16mm diameter and 8.3 g each) with a height of 40 meters (2500 pellets, 40: 0.016) to the lower pellet is equal to **20.7 kgF** only (203.1 N).
    - In the bunker of the same height (40 m), the pressure of the vertical layer of briquettes with a diameter of 30mm and a mass of 30g each (1399 briquettes) on the bottom briquette is 39.66 kgF or about **2 kgF/sq.cm**.
    - NLMK full-scale testing: CCS of vibropressed briquettes was in the range of **30-50 kgF/cm^2**
- In a high shaft blast furnace, the pressure of the overlying layers of charge on coke does not exceed **3-5 kgF/sq.cm**.

Compressive Strength

The compressive strength of briquettes is determined in dynamic conditions, ignoring the directly proportional relationship between the speed of the pressure plate and the final fixed value of the breaking load.



Liquid glass

bitumen

Tumble Testing

- The test result in the drum depends on the simultaneous action of **abrasive** and **crushing** forces. Depending on the design of the drum and the test conditions, the effect of these two factors on the same material is different.
- Tumble testing is a method for evaluating the strength of sinter and pellets, which consists in the mechanical processing of particles in a rotating steel drum and subsequent determination by a sieve analysis of the change in the particle size distribution of the sample, characterizing the ability of the ore to resist impact and abrasion.
- A sample weighing 15 kg is loaded into a drum with a diameter of 1000 mm and a length of 500 mm. The drum rotates at 25 rpm. On the inner surface of the drum along the entire generatrix of the cylinder, two equally spaced steel angles of size 50x50x5 mm are welded in the longitudinal direction.
- The testing of different materials in the same drum also differs both in intensity and in the predominance of one or another factor (abrasion and crushing). Therefore, despite the same type of transportation conditions for agglomerated raw materials (coke, pellets, sinter), the drum methods for their testing differ significantly.
- Testing of metallurgical coke and ore materials is carried out in devices of different overall dimensions (with the same diameter, the drum for testing coke is twice as long) and under different conditions. Drum speed, the test duration for pellets is twice as long, and the mass of the analyzed sample is three times less.

Tumble Testing

- A small volume (mass) of the pellets determines their high resistance to stress during drum testing. Therefore, for them, high values of rejection limits for abrasion (the share of classes less than **0.5 mm** is not more than **4-6%**, the share of classes more than **5 mm** is not less than **90-95%**) and strength are established.
- The sinter is a more easily destructible porous sponge-like material. Tumble testing for sinter after testing usually contains **55-65%** of a class **+5 mm** and **6-8%** of a class **-0.5 mm.**
- The pellets (**5-25mm**) and sinter (**5-40mm**) are quite heterogeneous in their particle size distribution and are distinguished by high porosity and fracturing. Since pellets and sinter are a granulated and then heat-treated mixture of ore and flux materials, they contain components that are different in their physical-mechanical properties.
- Test methods adopted for iron ore pellets in the drum are usually automatically and without any reason transferred to the briquettes.

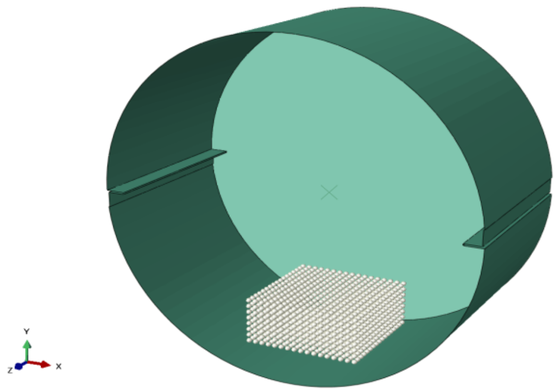
Tumble testing

- This approach does not consider significant differences in the structure of these agglomerated products (indurated pellets and cold briquettes with a binder). Test conditions and their results may differ significantly from the real picture of the destruction of briquettes in the technological cycle.
- Unlike pellets and sinter, briquettes are homogeneous in properties, size and shape agglomerated products with higher density, smooth surface and uniformity of physical and mechanical properties in the whole volume.
- This determines the different nature of the destruction of the briquette in the tumble testing. Briquettes have a greater mass than pellets, therefore, they will experience a stronger impact-damaging effect.
- Moreover, in the accepted methods of drum testing, the amount of materials is **15 kg**. The number of loaded briquettes and the volume they generate is significantly less than when testing pellets.

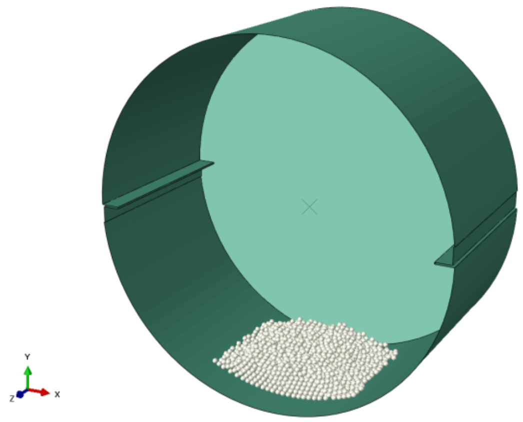
Tumble testing. Numerical Simulation

- Two types of agglomerated products were investigated: pellets with a diameter of 15 mm and briquettes with a length of 75 mm and a diameter of 25 mm. The cylindrical shape of the original briquettes is replaced by a spherical diameter of 41.3 mm with the condition of equivalence of the mass of the sample. The number of pellets in the 15 kg sample was 2360 pieces, briquettes - 90 pieces. Density of pellets 3600 kg/cub.m; density of briquettes 4500 kg/cub.m

Rotation of the drum in the field of gravity is determined with a frequency of 2.618 rad/sec, which corresponds to 25 rpm

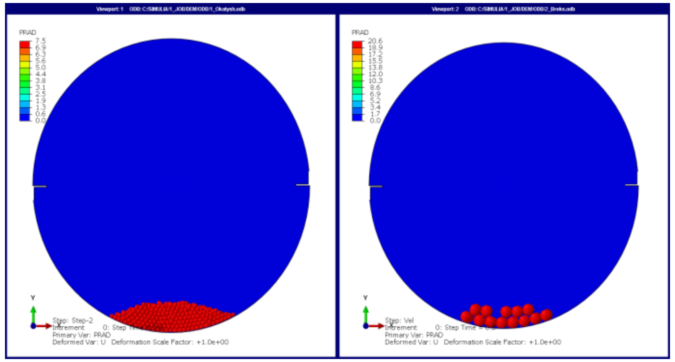


The initial position of the particles

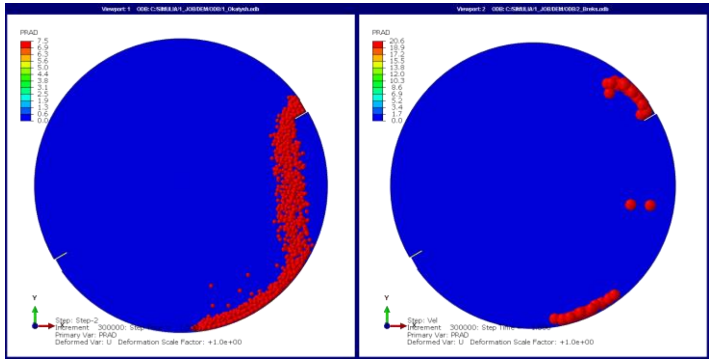


Particle position due to gravity

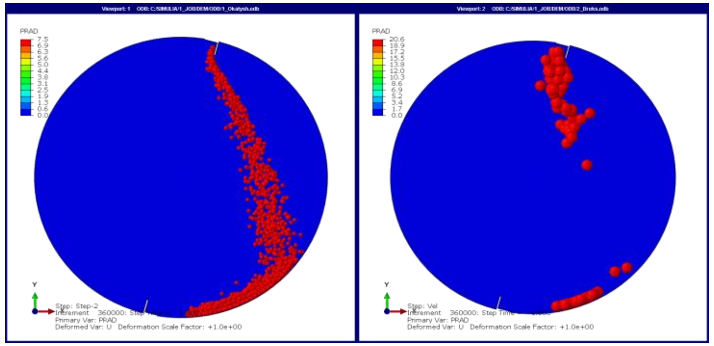
Tumble testing. Numerical Simulation



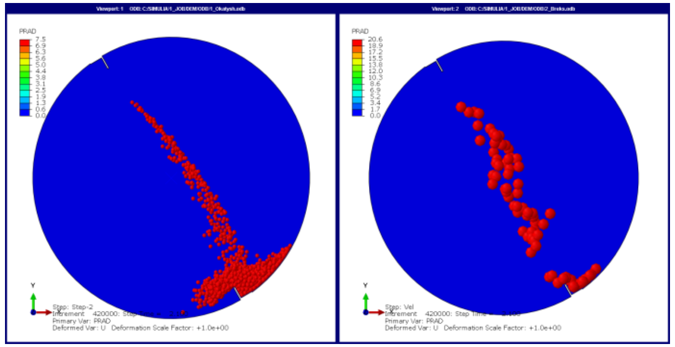
T=0 s



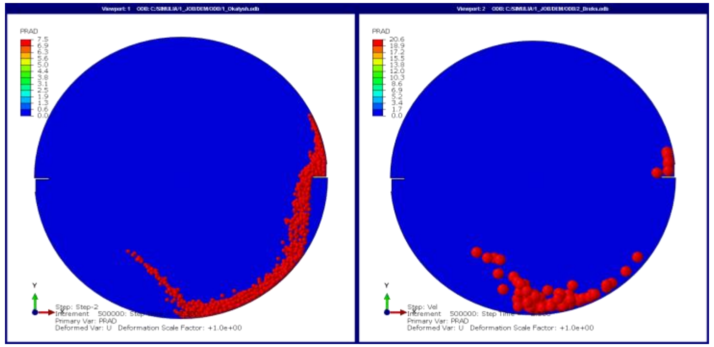
T=1.5 s



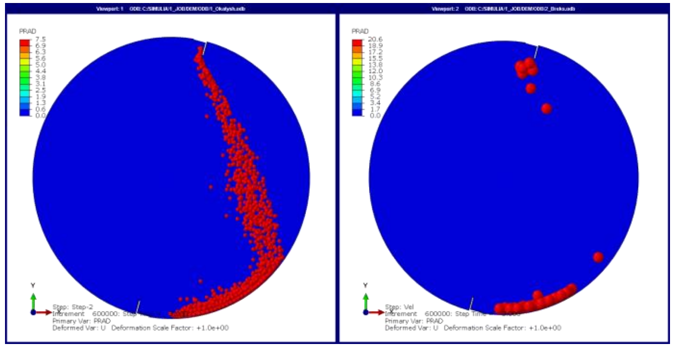
T=1.8 s



T=2.1 s

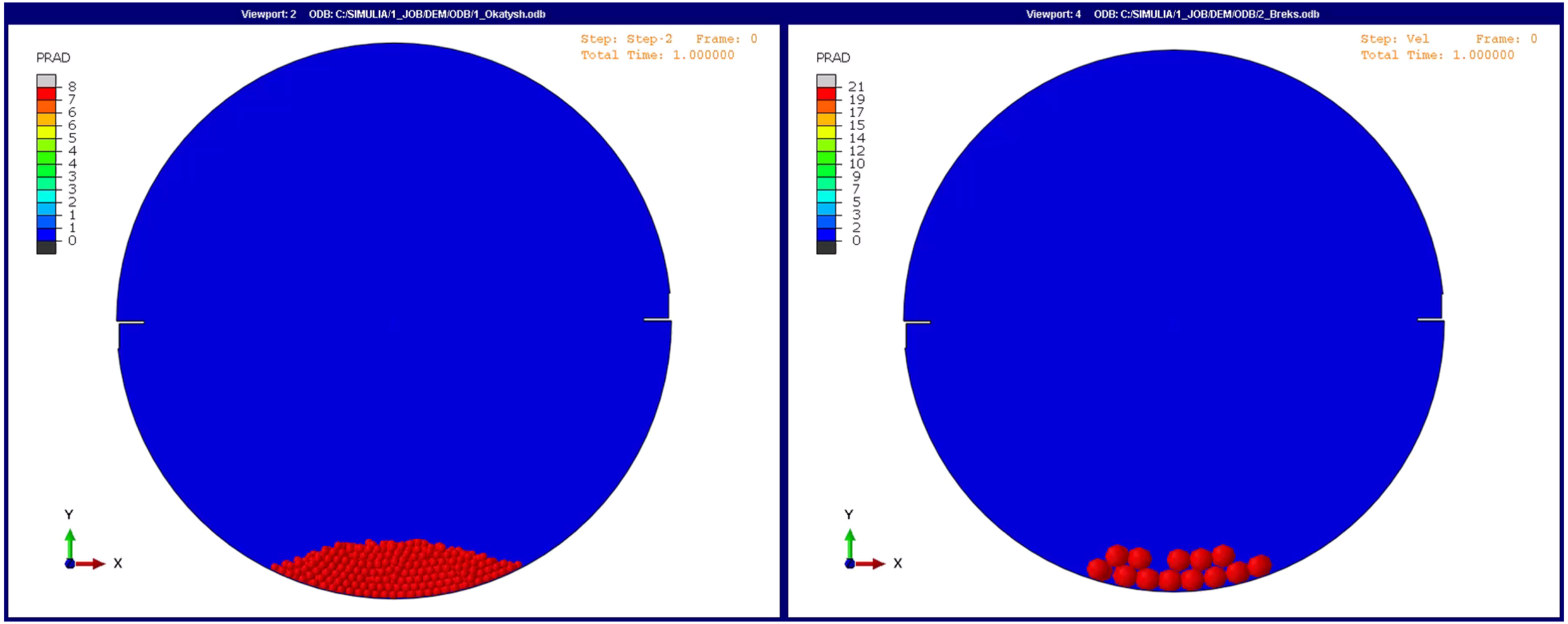


T=2.5 s

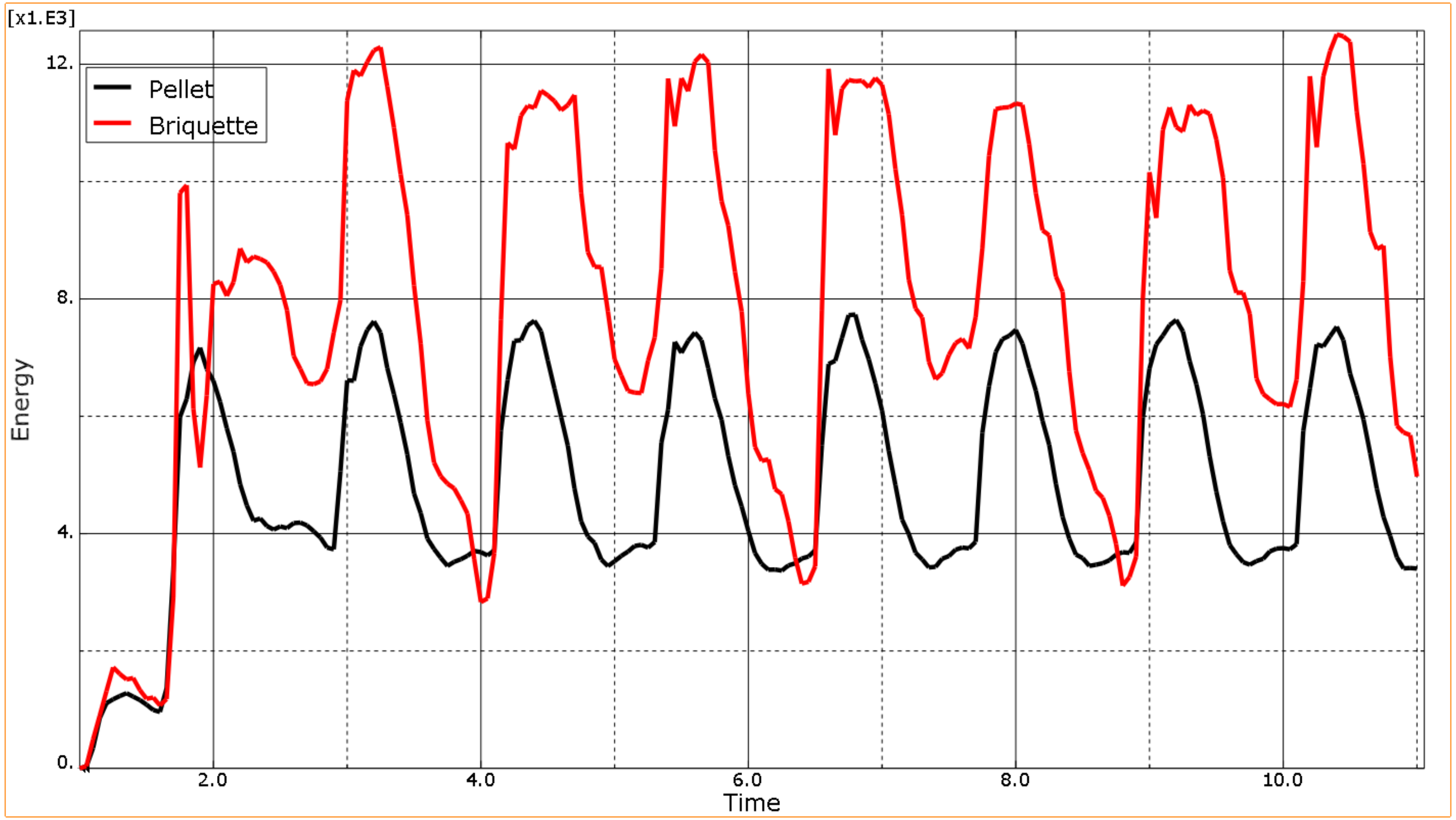


T=3 s

Tumble testing. Numerical Simulation



Tumble testing. Numerical Simulation



Change in the kinetic energy of particles; red – briquettes, black - pellets

Cold Strength and Hot Disputes

- The determination of the resistance of the briquette to dropping **can be carried out** according to the methods adopted for the **sinter and pellets**. The rejection limits should depend on the mass and size of the briquette.
- The method of determining the resistance to **compression** is not unified. The fixed values of compressive strength values depend on the intensity of the applied loads, therefore different results are obtained for the same material. The existing rejection limits for briquettes and pellets **are too high** and do not reflect the real load.
- Methods for determining the strength in a rotating drum, developed for sinter and pellets, **do not allow an adequate and objective assessment** of the strength properties of **briquettes**. The rejection limits (strength and abrasion) in quantitative terms for briquettes should be adjusted and not automatically transferred from the norms for **pellets**.

Cold Strength and Hot Disputes

- Usually it is required that the transportation of briquettes is carried out along the existing logistic trajectories of the metallurgical enterprise. In this case, there may be a need for a significant amount of loading-unloading operations and repeated dropping of briquettes from a considerable height.
- In such a situation there is a contradiction in the requirements for strength and value of the briquette, as a component of the charge, since increasing the content of the binder reduces the share of the main component in the briquette (iron, manganese, chromium, etc.). The briquette may have enough strength for its transportation to the furnace but be too strong for the metallurgical process.
- In our opinion, it is necessary to strive to create new “sparing” methods for transporting briquettes to the furnace, which will make it possible to fully utilize the metallurgical value of the briquette. It is possible to use special stackers to prevent briquettes from falling from a considerable height, etc.
- Metallurgists should more reasonably approach the formation of requirements for the mechanical strength of briquettes and establish separate rejection rates for them.
- Do not turn the delivery path of briquettes to the metallurgical unit into the migration of salmon.