THEORETICAL AND EXPERIMENTAL APPROACH OF FRICTION IN A MULTI-SAMPLES SAND-SLURRY TRIBOTESTER

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Abstract The „sand-slurry" method is wellknown among the abrasive tribotesting procedures [1-5]. Based on the DIN50322 standard defining the different tribotesting categories the number VI. category suggests the application of simplified test samples and conditions under control. At the Institute for Mechanical Engineering Technology a new sand-slurry tribotester was developed featured by the multi-samples holders taking different speed and load condition into account within one test rush. The resulted friction loss of the tests can be calculated by torque measurements and approaching calculation as well. The testrig and the method is used for testing different coated steel samples.

Keywords: abrasive testing, sand-slurry, multi-samples construction

1 INTRODUCTION

Several variations spread in case of sand-slurry tribotesters but they all correspond that the specimen moves with a given speed on circular orbit for example in sand with given granulometric composition as in abrasive medium.

The tribotester developed by the Institute for Mechanical Engineering Technology [6, 7] makes possible simultaneous measuring of many specimens in abrasive medium as well it also makes possible well defined evaluation but according to different conditions. All this happens according to the conditions of the VI. testing category based on the DIN standard further on.

Table 1. shows the detailed explanation of the categories.

2 CONSTRUCTION

Figure 1. shows the structure. The equipment can be connected to a central body with the base-plate made of plastic. The vessel containing the abrasive medium can be fixed to the base-plate. The body holds the motor guaranteeing the rotary motion of the vertical shaft in appropriate height that the abrasive medium should be able to set. The revolution of the driving motor can be changed according to the program so helping modeling the dynamic effects.

The shaft of the motor joins with worm gear mechanism which gear transmission is i=22,58. The working shaft to which the specimens to be abraded can be fixed in appropriate positions on which 3 pcs. cross – nippers with 4 arms can be found - in different heights relating to the base-plate - joins through clutch on the output side of the gear. The torquemeter sensor measuring the torque demand during operation can be found on upper part of the working shaft.

For each arm 3 pcs. altogether 4x3 pcs. specimens can be fixed to one cross nipper. It is an important characteristic of the cross-nipper that the specimens can be fixed in pairs on the arms closing 90^0 with each other, in different and different, altogether in 6 different positions relating to the centre of rotation. (Figure 1.) The cross-nippers are set in turned position compared with each other on the working shaft, they divide the circle to 30^0-sectors in top view.

Table 1. Disintegrating the tribological system to wear test categories

Category	Test method and load (DIN 50320, 3.2.2. point)		System structure (DIN 50320 3. point)	
I.	Operation respectively operation like test	Operation test (running test)	Original machine-elements	Complete machine/Complete equipment
II.		Test-bench test with complete machine or equipment		Complete machine/Complete equipment
III.		Test-bench test with part-unit, with main part		Complete part-unit or main-part
IV.	Model test	Test with unchanged machine-element or with reduced part-unit		Inportant machine-elements, reduced part-unit
V.		Test carried out on specimen with similar load	Model specimens	Test carried out on machine-elements with comparing load
VI.		Model test with simple specimen		Tests carried out with simple specimen

The vessel containing the abrasive medium – in case of demand – can be put into an outer container which can be filled up with cooling / heating water, so the heat-dynamics of the measuring process can be regulated, too. The abrasive medium can be overheated deriving form friction in case of high-speed abrasion.

As the specimens tested are placed at different radiuses (Figure 2.) and levels on the holding arms of the tribotester the effects of different speeds (Figure 3.) and pressure conditions (Figure 4.) can be studied.

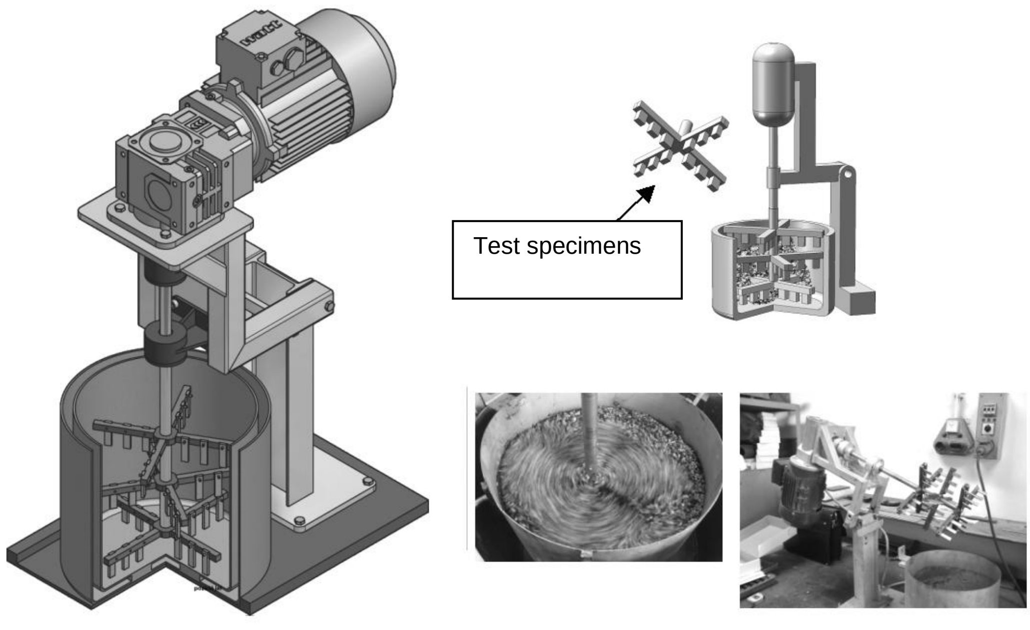

Figure 1. Modified “sand-slurry” module for abrasion measurements

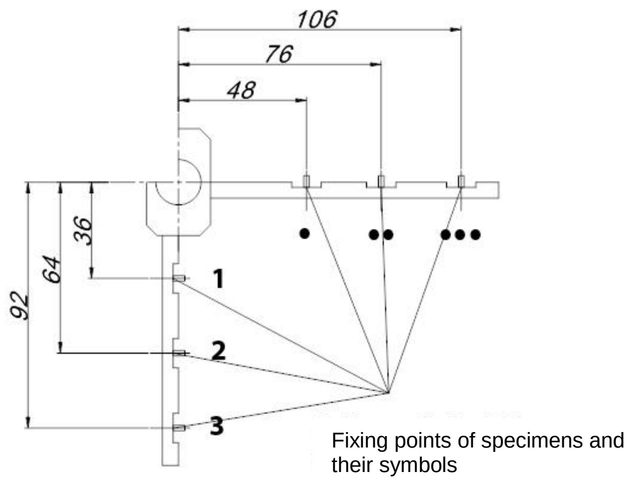

Figure 2. Specimens placed on different radiuses

The equipment is suitable to carry out tribological measurings with soils, sand, gravels and with other abrasive materials, so that many kinds of specimens can also be compared in one series of measuring at the same time, as well the effects of different speeds and pressures can be analysed, too.

3 INTERNAL RELATIONS OF THE TESTING SYSTEM

If the abrasive medium is soil or gravel mixture then more exact determination of the pressure distribution is needed because of the heterogeneous grain fraction of the granular aggregation as layers with different density can take place during mixing aggregation with different grain sizes.

The smaller grains accumulate in the lower layers in the empty spaces between the larger grains, so they increase the aggregation-density of the lower layers which results in raising the resistance of medium effecting the specimens. Knowing this is important at evaluating the abrasion results, at judging the abrasive effect of certain soils.

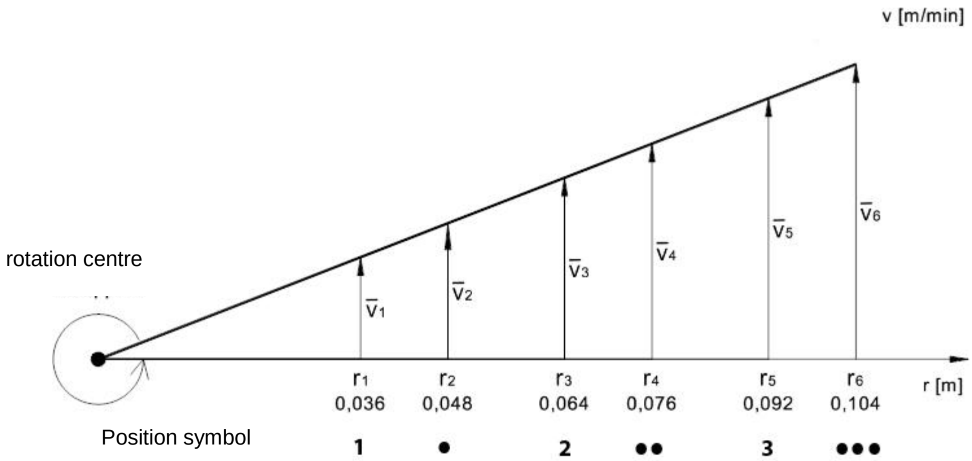

Figure 3. The positions of nests formed on the specimen-holders and speed vectors of the specimens at certain places in case of constant shaft revolution.

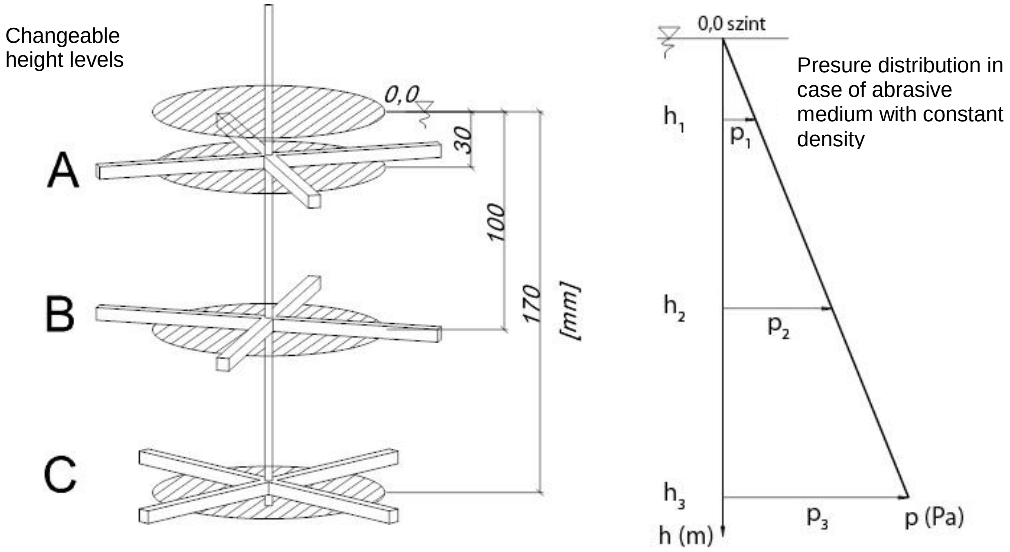

Figure 4. Changeable specimen-holder tool levels, and the pressure distribution changing linearly in case of abrasive medium with constant density.

The abrasive medium is very often heterogeneous abrasive medium with different grain sizes (for example: at using soil or gravel medium) which main characteristics are the followings: average homogeneous-density, clay-sludge content, grain fraction. The real aggregation density changes during measurings because of the lamination, which I make known in detail later.

The lamination of the abrasive medium, taking the changing medium-density (ρ, g/cm^3) into consideration at determining the pressure conditions can be possible according to the following (Figure 5.)

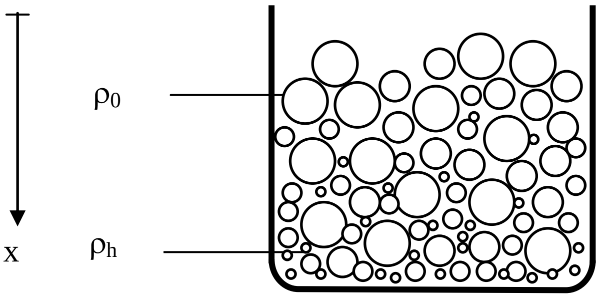

Figure 5. The changing of the abrasive medium aggregation-density (space filling, or “porosity”) the lamination of grains (grain distribution) during measurings.

The density of the grain material and of the real aggregation are different. The cause of this is the changing grain distribution in the aggregation, space filling, that is the “porosity” forming between the grains. The different space fillings have got an important role in the abrasion-test system at the abrasion evaluation of the samples in certain positions, because at the modified “sand-slurry” equipment it has to be cleared the pressure relations concerning the aggregations, beside knowing the speed relations (Figure 3.).

The theoretical analysis of the pressure relations of the tribological test system is presented in the followings.

The calculations suppose that it can be used an average friction coefficient characterizing the system (μ) that can be taken into account between the grains of the abrasive aggregation with changing composition and density as well as between the specimens and the different grains respectively between the specimen-holders and the grains alike.

According to the measurings of pre-tests the "porosity" forming as a result of lamination can be considered one-dimensional approximately, that is the "porosity" changes in vertical direction to the effect of the gravity, but horizontally (in radial direction) the space fillings is identical on identical levels, and aggregation-density arises corresponding to this.

The measuring experiences demonstrate that the aggregation-density approximately increasing linearly can be applied in case of most soil and gravel mixtures.

The function of the aggregation-density:

$$\rho(x) = \rho_0 + \rho_{grad} \cdot x \quad (1)$$

where:

ρ_0 – is the aggregation-density developed on the top of the aggregation (and that can be measured),

ρ grad – is the density gradient, that is the density increase along the unit height-change.

The x- variable gives the depth below the aggregation top of the testing place (Figure 6)

The compressing force between the grains that can be found on each other depends on the force of gravity affecting the parts above it.

This results compressing force increasing uniformly down in case of homogeneous mediums, it results classic hydrostatic pressure.

At determining the abrasive effect of soil and gravel with the modified "sand-slurry" equipment this on the other hand can be described with non linear function considering the density of the medium is not constant. The ρ(x) function describes the function of the medium density with changing density in the "h" height vessel.

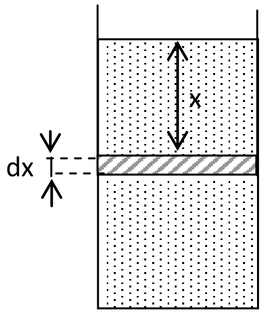

Figure 6. dx explanation from the aggregation top.

The force of gravitation effecting to an elementary dx (Figure 6.) thick layer in x depth from the top of the material aggregation (dx should be so small that the density change on the layer could be neglected, that is the ρ(x) average density should be able to be applied for the whole layer):

$$dF = dm \cdot g = (\rho(x) \cdot A \cdot dx) \cdot g \quad (2)$$

The pressure increase arising on the layer:

$$dp = \frac{dF}{A} = \rho(x) \cdot g \cdot dx \quad (3)$$

The pressure according to „h” height in the „h” depth is the sum of pressure increase of certain layers, so the pressure function:

$$p(h) = \int_0^h dp = \int_0^h \rho(x) \cdot g \cdot dx \tag{4}$$

As the „g” (the gravitational acceleration) is constant, so:

$$p(h) = g \cdot \int_0^h \rho(x)\, dx \tag{5}$$

The pressure function supposing the linear density change given by the (1) equation and taking into account „g” is constant:

$$p(h) = g \cdot \rho_0 \cdot h + g \cdot \rho_{grad} \cdot \frac{h^2}{2} \tag{6}$$

The average compressive force between grains can be determined knowing the pressure as well as depending on the layer aggregation-density in a given depth, with approaching the contact surface of real grain:

$$F_{ny} = p(h) \cdot A_e \tag{7}$$

where – A_e is the whole contact surface between grains depending on the porosity in the given layer.

The average, theoretical friction force with the help of compressive force in the given layer (in “h” depth) which can be taken into account in case of moving the whole layer:

$$F_s = \mu \cdot A_e \cdot g \cdot h \cdot \left(\rho_0 + \rho_{grad} \cdot \frac{h}{2} \right) \tag{8}$$

where – μ is the average friction coefficient between the grains in the “h” layer, concerning as constant in the whole material aggregation at the model.

The torque needed to measuring (to rotation) can also be approximated deriving from more components. The torque demand comes from the friction force arising on the samples (M_1) as an effect of given pressure and from the sample-holding arms (M_2). Furthermore the torque demand comes from the resistance of medium needed to move the grains partly at the specimens (M_3) partly at the specimen holding arms. Further on calculating with an average μ-value (between the grains and on the grain – specimen surface) the sum of the torques affecting certain samples which value is approximately:

$$M_1 = \sum_{i=1}^{3} \sum_{j=1}^{6} \left[\mu \cdot A_m \cdot g \cdot h_i \cdot \left(\rho_0 + \rho_{grad} \cdot \frac{h_i}{2} \right) \cdot r_j \right] \tag{9}$$

A_m is the real contact surface of the specimen depending on the porosity, the “i” index means the number of specimen holding arm (h_i means its “depth”), “j” means the serial number of the sample (r_j means its radius). In case of sample-holding arms the arm of the force of the torque deriving from the friction changes continuously because of it the elementary torque to an elementary section of the R-radius arm (dr) (Figure 7.).

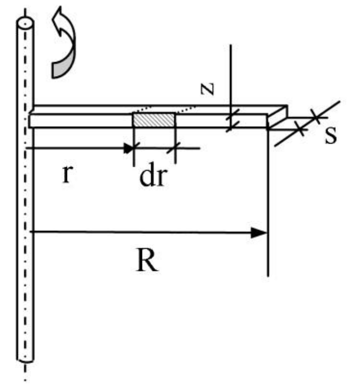

Figure 7. Torque of friction on the sample-holding arms

$$dM = dF \cdot r = \left[\mu \cdot g \cdot h_i \cdot \left(\rho_0 + \rho_{grad} \cdot \frac{h_i}{2} \right) \cdot s \cdot dr \right] \cdot r \tag{10}$$

where: “s” is the width of the sample-holder. The formule takes into account only the upper surface exposed to pressure, the friction on the lower surface taking place because of chaotic grain turbulence is neglected.

The total torque demand for all arms, disregarding the derivations:

$$M_2 = \sum_{i=1}^{3} \sum_{j=1}^{6} \left(\mu \cdot g \cdot h_i \cdot \left(\rho_0 + \rho_{grad} \cdot \frac{h_i}{2} \right) \cdot s \cdot \frac{R_j^2}{2} \right) \tag{11}$$

Taking into account technical literature models [7-9], the model based on motion of viscous mediums [9-11] can be applied in case of granular aggregations, too.

The braking force deriving from the resistance of medium to a moving body is generally:

$$\vec{F} = -C \cdot \vec{v}, \text{ vagy az } \vec{F} = -C \cdot v^2 \frac{\vec{v}}{v} \tag{12}$$

and can be taken into account with the above connections (the first in case of laminar, the second of turbulent flow). The factors (shape factor, end face, medium density c=k·A·ρ) reduced in the C-coefficient are quantities considered as constant values during motion. In case of using heterogeneous abrasive medium clear laminar as well as turbulent flow don’t develop, but the description of the forming of chaotic motion can be given by the power function similar with the quadratic rule of the speed, in the present model this is considered to quadratic.

To the magnitude of the braking force in case of specimens:

$$F_{i,j} = \frac{k \cdot A \cdot \rho}{2} \cdot \omega^2 \cdot r_{i,j}^2 \tag{13}$$

The total torque demand (M_3) to the resistance of medium arisen by the specimens:

$$M_3 = \sum_{i=1}^{3}\sum_{j=1}^{6} M_{i,j} = \sum_{i=1}^{3}\sum_{j=1}^{6}\left(\frac{k \cdot A \cdot \rho_i}{2} \cdot \omega^2 \cdot r_{i,j}^3\right) \tag{14}$$

where the density changes with the depth based on the presented model earlier it can be calculated in the $\rho_i = \rho_0 + \rho_{grad} \cdot h_i$ formule.

At the torque (M_4) of the force of medium moving arisen by the holding arms, the arm of the force of the torque changes together with the speed continuously, because of it the elementary torque (Figure 7.) to one elementary section (dr) of the R-radius arm:

$$dM = dF \cdot r = \left[\frac{k \cdot \rho_j}{2} \cdot (z \cdot dr) \cdot r^2 \cdot \omega^2\right] \cdot r \tag{15}$$

where: “z” means the height of the arm, the „k” value of the shape factor is constant, it is considered identical with the made known at the specimen

The common torque for all arms:

$$M_4 = \sum_{i=1}^{3}\sum_{j=1}^{6}\left(\frac{k \cdot \rho_i}{2} \cdot z \cdot \omega^2 \cdot \frac{R_j^4}{4}\right) \tag{16}$$

4 CONCLUSION

To sum up, the torque demand needed to operate the equipment, from the above:

$$M = M_1 + M_2 + M_3 + M_4 \tag{17}$$

As the real “M” can be measured on the driving shaft, furthermore the ρ_i can be measured on the basis of sampling so there is a possibility by indirect mode to compare also the simplified, numerical friction conditions which the former equipment haven’t guaranteed.

The test equipment was successfully used for abrasive testing of different hot-dip galvanized layers on steel specimens. Presently, the construction is used for different food industrial tribotesting.

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