Novel Analytical Method to Determine Factors Causing Unwanted Sticking of Glued Wood Particles onto Machinery Parts*

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Abstract

''Sticking'' of glued particles onto machine parts (blender, conveyor, forming station) during wood panel production increasingly occurs when applying low-emission aminoplastic adhesives. Therefore, a new and reproducible method to investigate sticking effects was developed. With this setup, both drying out of the adhesive and the tendency of particles to adhere onto machinery components can be described. The method consists of a rotating cylinder made out of different materials and of diverse surface roughness in order to simulate machine parts, which runs over a wood surface where resin is applied. The wood surface represents the wood particles. The temperature of the wood surface and the ambient air as well as the relative humidity can be controlled. Before starting the experiment, a defined amount of adhesive is applied onto the wood surface and with this a ''glue line'' is built up. Drying out of the adhesive causes an increase of the rolling resistance up to a peak value. Afterward, an abrupt or gradual decrease of the rolling resistance is observed. This rolling resistance is accurately measured and recorded. Using the approach described above, influences of different materials, climate conditions, surface temperature and roughness, as well as adhesive properties can be observed. The initial results provide strong evidence that climate conditions of the ambient air as well as material and surface properties of machine parts show a significant contribution to the phenomenon.

Owing to increasingly rigid formaldehyde restriction guidelines, a new generation of low-emission formaldehyde-based condensation resins was developed. To meet the emission requirements, significant changes in the resin chemistry have been necessary. These changes include reduction in molar ratio formaldehyde/urea, changes in solid weight content, pH value, and other factors. However, the modification of resin recipes is also accompanied by changes in tacking and drying out behavior. These behaviors may cause problems in board production because of sticking of resinated particles onto machinery parts.

Tack is the property of an adhesive to enable formation of a bond immediately on contact with another surface, which can be an adherend or another layer of adhesive (European Committee for Standardization 2005). Drying out is the loss of water from the adhesive system. This effect is influenced by various factors and results in either a completely dried resin or the dry surface film of a resin layer. During the

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drying out procedure, tack forces evolve. Two different forces influencing the resinated particles exist: (1) the so-called (cold) tack forces bind wood particles to each other and can be strong even in the dried condition, and (2) the unwanted adhesive bonding of resinated particles to other materials. This latter force is dominant in non–dried-out adhesion systems. Changes in tacking behavior may also cause more of this adhesive bonding. This means resinated wood particles stick on surfaces of various machinery parts. Whereas ''tack'' is considered to be positive as it helps form and stabilize the pre-pressed mat, the adherence of resinated particles to conveyor, blender, and forming station parts is an undesired effect (Kantner et al. 2010). It results in more time-consuming cleaning efforts, which negatively affect production process efficiency. This effect, which more often occurs with low-emission aminoplastic resins, is called ''sticking,'' and it develops while the adhesive is drying out.

To describe ''sticking'' properly, the change of tacking in association with drying out of the resin needs to be followed. To describe the tacking behavior of an adhesive, various test methods have been established.

A more complex testing method is the probe tack test (American Society for Testing and Materials [ASTM] 1988) especially developed for testing pressure-sensitive adhesives, i.e., those adhesives that are permanently tacky in a dry state. Results gained from this test are influenced by time, force, temperature, and formation of resin filaments (Zosel 1998). Another method used to describe the tacking behavior of pressure-sensitive adhesives is the rolling ball method (ASTM 1989). It is heavily influenced by weather conditions, size of the rolling ball, and the thickness of the adhesive layer. These influencing factors limit this method with respect to reproducibility, especially by comparing results of different laboratories (Roberts 1997). Moreover, the liquid aminoplastic adhesives investigated in this study are very different from pressure sensitive adhesives.

A well-known and simple approach is the so-called finger-dipping method. A resin is spread out on a glass plate and the increasing adhesive strength is tested with a finger dipped repeatedly onto this adhesive layer. The result of this test is a subjective estimation of the development of sticking behavior. However, the basic idea of finger-dipping is quite useful. Nevertheless, the results gained are not sufficiently reproducible and therefore a more sophisticated test is demanded.

For a more reproducible test, the increasing stickiness has to be measured by means of a sensitive device. For this purpose, a new test method based on a rheometer was invented. Instead of a rotating tool for measuring viscosity, a wheel was mounted to the rheometer; it rotates in a circle on a high-density fiberboard, and a thin layer of applied adhesive resin mimics the resinated wooden surface of a particle. After applying the resin onto the surface of the board, the increasing adhesive strength during the drying out period causes an increased resistance to rolling. This increase can be measured with the rheometer as a moment of torque. The original test setup was based on a rheometer MCR 300 (Anton Paar GmbH, Graz, Austria) with a rotating wheel fixed on a cantilever that guided the wheel along a circular trace over a high-density fiberboard (Kantner et al. 2010). This initial approach included two limitations. First, because of its weight, the wheel is pressed onto the resin wetted surface of the fiberboard. This contact pressure of the wheel may change during the test if the joint between the cantilever and the center spindle is not supported by ball bearings. Change in contact pressure also changes the resistance to rolling, and therefore the torque recorded by the rheometer is affected. Second, the radius of the rotating wheel was 30 mm, which caused a lot of roll shear effects during cycling around on the fiberboard, which can also bias the test results.

To evaluate the influential factors on the sticking phenomenon of aminoplastic resin, a reproducible and reliable testing method is needed. The objective of this study was to improve the method described by Kantner et al. (2010) and evaluate potential influential factors. The assumption was that humidity and temperature influence the phenomenon and causes sticking in the particleboard production plant. Therefore, the test setup was improved to measure rheology under different climate conditions. To validate the experimental results of the rheometer measurements, temperature and humidity were also continuously logged at an industrial particleboard production plant.

Materials and Methods

Rheometer setup

In order to minimize variation of the contact pressure of the wheel, a ball bearing double-sided cantilever with a counter weight is now used. Additionally the wheel was downsized to a width of 8 mm, which gives less shear effects and more reproducible results.

Figure 1 shows the test setup with the wheel mounted on the double-sided cantilever with the counter weight. Before starting the measurement, the double-sided cantilever is equilibrated. The resistance to rolling on the fiberboard surface before applying the resin and, hence, the monitored torque are reduced to a minimum by this adjustment. Thus, the attraction of the wheel to the fiberboard surface is mainly caused by the stickiness of the resin and not by the weight of the wheel as such. Furthermore, changing the weight of the wheel during the test (adhesive film on the surface) is negligible (less than 0.06%). Therefore, this has no significant influence on the measurement and the counter weight does not need to be adjusted.

To investigate the influence of temperature and relative humidity, the new test setup was equipped with air conditioning, which allows for testing at constant temperature and relative humidity. In this climate chamber, the

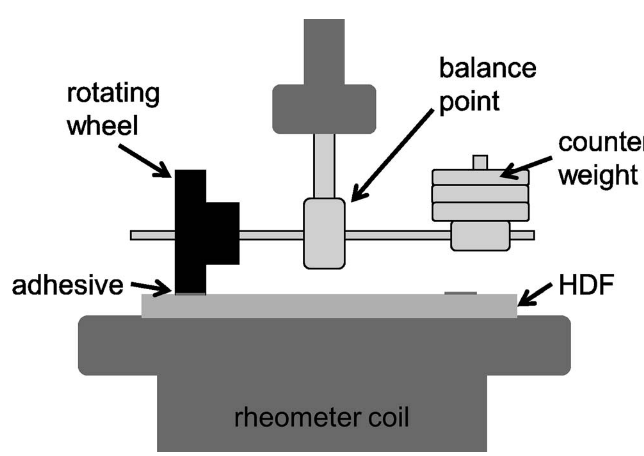

Figure 1.—Construction of rheometer installation (schematic). HDF = high-density fiberboard.

relative humidity can be varied between 25 and 75 percent with a standard deviation of 2 percent. The temperature can be varied by the heating coil of the rheometer Bohlin CVO 50 (Bohlin Instruments GmbH, Mühlacker, Germany) between 10°C and 90°C.

All results presented in this article were gained by using a polypropylene wheel for the sticking test setup described above. Before starting the test run, the wheel was warmed up to the same temperature as the boards, preventing cooling down of the adhesive film at the beginning of the test.

Fiberboard base plate

Corresponding to the method presented by Kantner et al. (2010), a fiberboard is placed onto a temperature controlled base plate. The fiberboards used were cut from a high-density fiberboard to a size of 90 by 90 mm. The boards were sanded (180 grit) and stored under standardized climate conditions (20°C ± 2°C; relative humidity: 65% ± 4%). Because of the possible influence of roughness on the sticking behavior, surface roughness was measured by means of a perthometer (Taylor Hobson, Form Talysurf Series 2). By comparing the standard deviation of arithmetical mean deviation of the roughness profile (R_a) and maximum height difference in measurement (R_t), the surfaces were divided into the three categories ''even,'' ''average,'' and ''rough.'' For the tests, only boards classified as ''average'' were used and put into an oven 48 hours prior to the tests in order to warm up to the defined temperature.

Particleboard binders

For the study reported here, urea-formaldehyde (UF) and melamine-urea-formaldehyde (MUF) particleboard resins, developed to fulfil the requirements of CARB (formaldehyde emissions from particleboard maximum 0.09 ppm when measured according to ASTM E1333 [ASTM International 2010]) as well as F**** (average formaldehyde emissions from board $\leq$0.3 mg/liter while no single measurement exceeds 0.4 mg/liter when measured according to JIS A 1460 [Japanese Standards Association 2001]), were used. The resins were stored at standard reference atmosphere (20°C ± 2°C). Before the sticking test was performed, the viscosity of the adhesive resin was measured with a cone-plate rheometer setup (20°C, 200 s^{-1}). Measurements were conducted over the storage time of the resin showing the expected increase of viscosity with time.

Resin sticking was measured after the addition of a 20 percent aqueous ammonium nitrate solution as hardener. The total amount of solid hardener was 3 percent in relation to the solid weight content of the resin. From this resin-hardener mixture, 0.2 mL was applied with an injection onto the high-density fiberboard while the wheel was in motion. The defined amount of resin was distributed in eight little droplets along the circular track. The optimized amount of 0.2 mL was selected after a long line of test measurements in order to have enough resin to get a complete track; exceeding this resin amount with an 8-mm wheel leads to resin fibers influencing the moment of torque.

Results and Discussion

Figure 2 shows a schematic curve of increasing and decreasing torque by using the test setup described above. All curves measured follow a similar trend; however, time course and maximum moment of torque greatly vary depending on resin used and process conditions chosen. These curves can be divided into four distinct sections. (i) The first part of the curve describes the resistance to rolling and friction of the wheel rotating on the fiberboard surface before the application of the resin. Idle running of the wheel causes a more or less constant moment of torque slightly varying with the roughness of the fiberboard and the rotating wheel. The constant level of the moment of torque can be easily subtracted from the values gained during the test. The rotating adhesive is homogeneously spread along the circular trace on the fiberboard by the wheel resulting in a slight increase of the moment of torque. This increase reflects the moment of torque needed to break the resistance of rolling the wheel on the liquid adhesive film. At this time the adhesive is fresh and drying out has not yet started. (ii) In the next part of the curve, a steep increase in the moment of torque can be observed, reflecting the increase of the

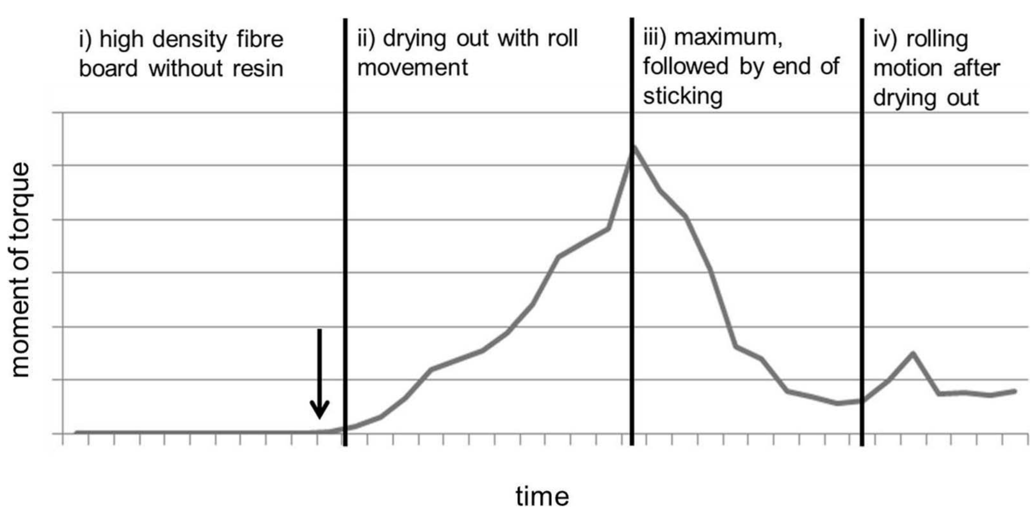

Figure 2.—Schematic drawing of the sticking behavior divided into four distinctive sections: (i) roll resistance, (ii) increase in stickiness, (iii) decrease in stickiness, and (iv) surface roughness with dried out adhesive resin layer. Arrow indicates resin application.

resistance of rolling caused by drying out of the resin. The adhesion strength of the adhesive resin develops while the adhesives starts to dry out. This phase is partially accompanied by tear outs of particles of the fiberboard. (iii) Stickiness of the resin reaches a maximum point and an abrupt decrease of the moment of torque can be observed. The adhesive is almost dried out and loses its adhesion strength. (iv) In the final section, the curve is characterized by a gradual downward slope until the end of the sticking test. At this point, the adhesive is completely dried out and no more adhesion strength can be observed. During this last phase, it is typical to observe an oscillation of the moment of torque. The remaining peaks in torque are caused by tear outs from the fiberboard. Depending on the stickiness of the resin, different percentages of fiber tear out can be observed resulting in a higher roughness.

Figure 3 shows the influence of the varying temperature of the fiberboard on the sticking behavior. The two curves recorded during the test were measured at different temperatures, i.e., 25°C and 52°C, but at the same relative humidity of 50 percent. The moment of torque was measured while the resin dried out. The resulting curves show the development of stickiness of a 4-week-old UF resin. The curve depicted is an average curve gained from nine separate measurements, derived from three resin batches, each measured in triplicate. Within these curves, the maximum moment of torque shows a standard deviation of 20 mNm. The maximum moment of torque for 25°C can be measured after 46 minutes as 65 mNm. The resulting curve for 52°C shows a strong increase at a much shorter time with a maximum already reached after 11 minutes. The maximum moment is 2.5 times higher at 52°C than at 25°C. This implies that adhesion measured as rolling resistance increases with temperature. The higher the temperature, the faster the drying out of adhesive occurs and, hence, the shorter the duration of the measurement.

Besides the influence of the temperature, the relative humidity also influences the measurement, as shown in a comparison between 50 and 60 percent relative humidity. The fiberboards were warmed up to 43°C. The age of the MUF resin used in these measurements was 15 days. As shown in Figure 4, a rather small change in relative humidity significantly changes the monitored course of the moment of torque. The curve shown here is an average curve gained from 12 measurements, from four resin batches each measured in triplicate. Within these curves, the maximum moment of torque shows a standard deviation of 35 mNm. While the maximum is achieved after 7 minutes for 50 percent relative humidity, the maximum moment of torque for 60 percent relative humidity is measured only after 25 minutes. Besides the time shift, the maximum torque is also significantly influenced; the maximum point of the curve at 50 percent relative humidity is 2.5 times higher than at 60 percent relative humidity. This enormous change in the curves at the same temperature reflects the importance of relative humidity on the sticking effect. The drying out time is reduced to less than one-third by a rather small increase in relative humidity from 50 to 60 percent.

The relative humidity, being such an influential factor, was also followed by real life data. The climate conditions were permanently logged within the continuous particleboard production plant with a Voltcraft DL-120TH (produced by Conrad Electronic, Hirschau, Germany). The relative humidity in the plant depends not only on weather conditions, but for a larger part also on the use of different resin types and amounts. Figure 5 depicts a representable example of 2 days of these ongoing measurements, in which both MUF and UF resins were applied. MUF-bonded boards have higher resin consumption. Assuming in this comparison that similar temperature and air exchange are used, a higher relative humidity will develop because of the higher moisture content of the MUF-resinated particles compared with the UF-resinated particles with lower resin consumption. The average relative humidity for the MUF board production was 54.5 percent on day 1 and, because of weather conditions, 62.5 percent during day 2. This difference seems to be negligible, but from Figure 4 we learned that this is not the case, as the sticking moment of torque greatly varies. Indeed, on day 2 no sticking problems occurred, whereas on day 1 with the lower relative moisture content, sticking was evident. This proves that even small changes in relative humidity of the surrounding air lead to

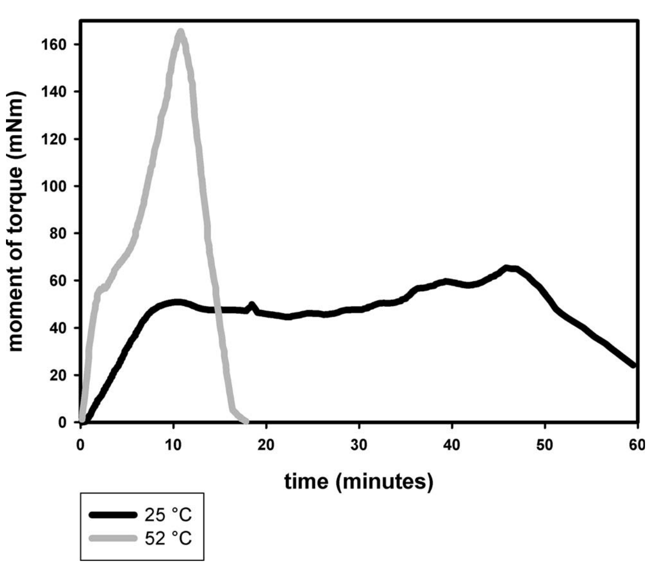

Figure 3.—Influence of the temperature on the sticking curve at constant relative humidity of the surrounding air.

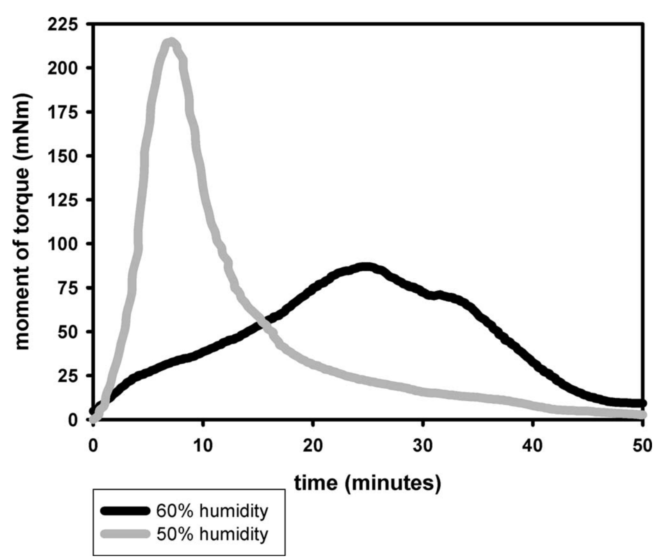

Figure 4.—Influence of the relative humidity of the surrounding air on the sticking curve at constant temperature.

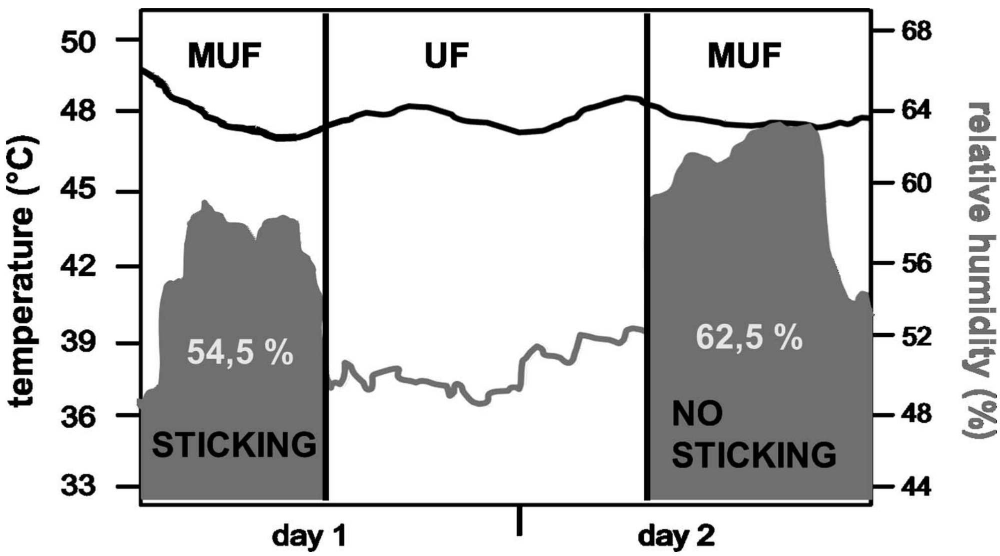

Figure 5.—Climate log from the production line. Upper curve: temperature; lower curve: relative humidity. MUF = melamine-urea-formaldehyde; UF = urea-formaldehyde.

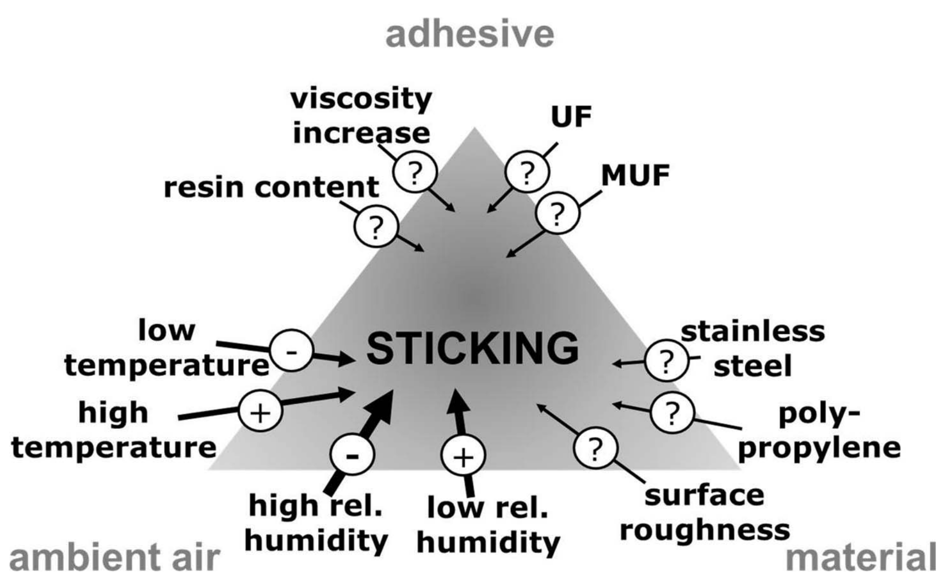

Figure 6.—Factors influencing the sticking behavior. + = raises sticking; – = decreases sticking; arrow thickness = intensity of influence; ? = subject for further investigation (still in progress); UF = urea-formaldehyde; MUF = melamine-urea-formaldehyde.

high variation in the drying out behavior of adhesives. The consequences for the sticking evolution could be convincingly demonstrated using the rolling rheometer approach (comparing Figs. 4 and 5). These results prove that the analytical method presented here is appropriate to describe sticking in practice.

From this first study, conclusions about influences of temperature and relative humidity on the sticking effect can be drawn. Whereas a high temperature increases sticking, a higher humidity decreases the maximum moment of torque significantly. Clearly, other parameters will influence the sticking behavior, such as surface roughness, wheel material, and resin characteristics, e.g., viscosity, resin type, and amount of resin used (Fig. 6). Further research efforts are needed to investigate such additional influential factors in more detail.

Conclusions

The method described herein measures the stickiness of an aminoplastic adhesive and its time dependence in a reproducible way. It is a useful approach to describe the induced adhesion strength between a wooden surface with an adhesive layer and a second surface of different material occurring while the adhesive dries out. The method can be used to reliably record the development of sticking with time while controlling various influential factors.

The test results show a significant influence of temperature changes. A large influence is attributed to changes in relative humidity of the surrounding air and the resulting moisture content of the surface of the resinated wood surfaces. Other parameters like resin amount on the board, surface roughness, or the viscosity of the applied adhesive will also influence the sticking behavior. As shown in detail for temperature and relative humidity, the strength of each factor on sticking will be different.

Besides this, our measurements show that various influential factors in the production process on the sticking behavior can be put into models, which may lead to novel prediction models of stickiness. In order to fully understand the influences of the various factors, however, further research is needed. Currently, research is ongoing to investigate additional influential factors and to relate this laboratory test to practical experience.

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