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Adhesion and cleanability of surfaces in the baker's trade

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ABSTRACT

Several surfaces relevant to the baker's trade were evaluated regarding the normal acceleration needed to remove either wheat flour particles or wheat dough using the centrifuge method. The findings were compared to surface properties and parameters derived by CLSM measurements. Stainless steel sheets of different roughness were found to be strongly adhesive. Conveyor belts appeared to be easily assessable regarding dough adhesion on a visual basis: Shiny surfaces adhere strongest and values scatter the widest, macroscopically structured bands gave lowest and steadiest tensile strength. In proving cloths the critical surface element for dedusting was found to be the valley portion, for easy dough separation it was the maximum height of the surface profile peaks. In both cases cotton appeared to adhere less compared to polyester. Requirements can be accommodated to optimize textiles in use in the baking industry.

1. Introduction

Increasing demands in hygiene for food production in recent decades did not forgo the baker's trade. Here stickiness of dough poses a big challenge. One aspect is generic contact of dough with equipment's surfaces. The hygienically more relevant and technically most interesting contact occurs while dough pieces are resting to rise. To facilitate yeast activity and prevent defects in the bread roll's crust rising is done in a warm and humid atmosphere – ideal conditions for mold fungal growth when dough and flour residues serve as nutrient. Thus frequent cleaning and replacing of dough carrying textiles is compulsory.

Textiles are widely used in both artisan and industrial scale because they provide good ventilation and prevent or reduce liquid deposition at the contact boundary. When flour is used as a separating agent, deposits are formed and excess flour spreads over the equipment only relocating the hygienic issue.

The most prominent phenomenon in dough adhesion is tackiness – the property to instantly bond to any surface in contact without further thermal or chemical activation. This behavior is known from pressure sensitive adhesives and has been summarized in this context by Heddleson et al. (1994). Chen and Hoseney developed a widely spread method for stickiness determination employing a strain controlled force-deflection measurement (Chen and Hoseney, 1995). Wang et al. stated a strong correlation between stickiness and viscoelastic properties of dough (Wang et al., 1996), Jekle proved this with small amplitude oscillatory shear experiments (Jekle and Becker, 2011). Bockstaele conducted creep-recovery measurements (Van Bockstaele et al., 2011) and Ghorbel tested actual dough adhesion on solid surfaces (Ghorbel and Launay, 2014). All these studies rather focused on varying dough properties; new in this paper is the correlation of dough adhesion with mechanical surface properties.

Adhesion between particles and surfaces is a common phenomenon, which influences or determines not only appearance, properties, and handling of particulate solids but also the cleanliness of equipment and surroundings. In dry conditions van der Waals forces usually dominate adhesion; they were theoretically derived by Hamaker (1937) from a molecular and by Lifshitz (1956) by a continuous viewpoint. Rumpf (1975) and Rabinovich et al. (2000a,b) adapted their geometrically simple models to ideal rugosities, Greenwood and Wu (2001) and Kumar et al. (2013) expanded it to rather realistic roughness, whereas Johnson et al. (1971) allowed adhering particles to deform elastically in their model thus linking the work of adhesion to the surface free energy of the particles via a certain contact area.

Corresponding to the simple theoretically dealt with geometries experimental work originally focused on easily comprehensible smooth spheres and flat surfaces (Corn, 1961). Fuller and Tabor (1975) described the influence of surface roughness, still using spherical probes. Salazar-Banda et al. (2007) compared the

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adhesion of reasonably round manioc starch particles to that of unevenly fractured phosphatic rock particles and Weiler et al. (2010). investigated the auto-adhesion of evenly corrugated, specifically synthesized dextran particles. Higher complexity of the contacting bodies' geometry requires an increasingly thorough knowledge of the respective contact zones and of the contacting particles' configuration and orientation on the substratum for a classical data interpretation.

Of the common experimental tools for measuring adhesion forces, surface force apparatus and atomic force microscope yield very precise values of interaction forces, but only for one single particle in one specific orientation, which serves its purpose for monodisperse spheres on smooth flat surfaces. Statistically broader results can be obtained with many particles at once, using the vibrating disk or the centrifuge technique. The former depends on mechanically stable and relatively flat substrates, whereas the latter provides reliable, constant accelerations in a simple centrifuge setup.

Experimental interest was found in pharmaceutical development for inhalation drugs (Deboer et al., 2003; Podczeck et al., 1996a,b; Weiler et al., 2010), for capsule filling (Podczeck, 1999), or for cleaning: the micro-electronics industry (Hein et al., 2002) needs molecularly smooth surfaces, which resemble idealized geometries; the work of Hartmüller et al. (2014). on particles as separating agent in offset printing also discusses the distribution of contact points between particles and substratum.

Form closure gets relevant if particles can migrate into holes or behind undercuts. Theoretically form closures can transmit extremely large forces. In this work flour particles deposited in the surface structure of textiles and got stuck there. Resulting forces were probably overcome by instabilities in mechanical balancing and deformation of the fabrics' surfaces.

Although comparatively weak, van der Waals force can dominate adhesion of larger bodies, especially when one is soft. Softness then allows one body to deform, to adapt to the second's surface, and to wet-out – reducing surfaces and thus minimizing surface free energy. Bond formation speed and capability on rough or uneven surfaces depend on the rheological softness at relatively low deformation speeds. The bond's strength is usually determined by faster deformations' forces, while the failing behavior depends on the ratio of viscous to elastic forces – adhesive fracture for low or cohesive fracture for high quotients. This phenomenon is known from or as pressure sensitive adhesives. Their contact strength increases during the first minutes to hours due to further and further wet-out on the substrate (Paul, 2011).

This paper describes the interaction of fractured shape wheat flour particles with rough surfaces (Section 3.1) and with fuzzy surface textiles (Section 3.2) on the one hand. As a technological problem to work on, wheat flour particle removal from proving textiles is covered. On the other hand dough adhesion is quantified, again, on different surface types including proving cloths (Sections 3.3–3.5). Combining the findings recommendations for improved dough contact surfaces can be put. The work was conducted in close collaboration with the Chair of Brewing and Beverage Technology at Technical University of Munich (TUM).

2. Materials and methods

2.1. Multi-scale structured surface: construction of textiles

The production of textiles creates large two-dimensional structures out of small fibers or filaments in several steps, with each step adding degrees of freedom to the choice of properties of the final product. Since each step is related to another size scale, the textile's surface can be structured specifically in multiple scales.

Here only woven textiles were used; their construction is now sketched out (compare Figs. 1 and 2): Fibers may occur naturally as in case of cotton or be melt-spun as in case of polyester. While latter possess a circular cross section, smooth appearance, adjustable diameter, and theoretically infinite length, cotton fibers grow in specific sizes with lengths of up to 25 mm, rather rectangular cross section, and curly appearance. To yield a long enough yarn these fibers need to be spun by twisting. Endless filaments can also be spun by parallel grouping, or when thick enough directly used as monofilaments. The resulting simple yarns can be strengthened by doubling or plying, which again means parallel grouping or twisting, respectively. The actual weave is a regular pattern of cross over and cross under of perpendicular warp and weft (recognizable in Fig. 2). Every weave can be adapted in the number density of threads, and the incorporation, which is the ratio of the stretched to the apparent length of a thread. Common finishing of textiles is shrinking (for cotton) or thermosetting (for polyester) which anticipates dimensional changes otherwise occurring at the first washing.

2.2. Dough

Wheat dough is a spongy system of a wet gluten network filled with starch granules and – given the case – gas bubbles. The network comprises of hydrated protein strands of cross-linked glutenin and gliadin molecules. The elasticity allows a dough piece to keep its shape before baking; the microscopic structure helps to retain fermentation gases for leavening.

Dough forms when wheat flour is mixed with water and kneaded: the protein content hydrates and swells, then glutenin and gliadin molecules cross-link via disulfide bonds forming the actual gluten. Kneading aims towards a smooth dough with a favorable degree of crosslinking, protein strand alignment, and network formation. Mechanical work is capable of breaking the crosslinks again, this is known as over-kneading.

2.3. Wheat flour particles

Flour particles represent a typical soiling in the baking industry; their removal was investigated using the example of wheat flour of type 550 (according to DIN 10355 (Norm, 1991)) of Rosenmehl

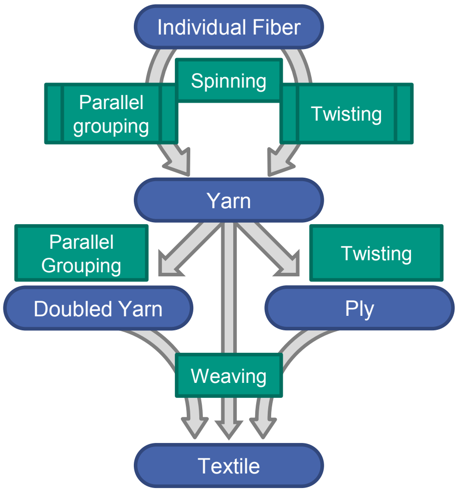

Fig. 1. Simplified scheme for the construction of woven fabrics. Primary, individual fibers need to be interlocked to form a stable cloth, which may be achieved by twisting and weaving. Multistep construction offers the possibility to structure differently sized elements independently.