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Journal of Food Engineering 70 (2005) 165–170
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Cutting forces in foods: experimental measurements

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Received 26 May 2004; accepted 20 September 2004

Abstract

Investigations into parameters affecting cutting forces in foods were undertaken to identify basic trends such as the relationship of cutting forces to cutting speeds and food temperatures. A simple plain blade was used to cut three typical foodstuffs (cheese, bacon and beef) at three feed speeds and three temperatures. After each cut the blade was passed through the product a second time to measure forces indicative of friction on the sides of the blade.

Cutting forces for cheese decreased with increasing temperature and increased with cutting speed. The relatively homogeneous nature of the samples resulted in consistent and repeatable measurements. For bacon, variable salt content gave rise to different ice contents and thus hardnesses in samples at the same 'frozen' temperatures. Layers of fat and muscle boundaries also produced marked deviations from the average forces. Force results were therefore scattered but increased with decreasing temperature. The effect of cutting speed was not consistent for all forces, but higher speeds generally produced higher forces. For beef, there was a marked difference between frozen and unfrozen samples but little difference between samples at different unfrozen temperatures. In unfrozen samples, cutting speed had little effect on forces, whereas faster cutting speeds produced higher forces in frozen samples. The proportion of total cutting forces made up by friction was found to be consistent over all temperatures and speeds for cheese and bacon, but markedly higher in the frozen beef samples compared to the unfrozen samples.

Keywords: Cutting force; Friction; Cutting speed; Temperature; Food

1. Introduction

The design and operation of food cutting equipment and associated processes such as tempering to achieve suitable physical properties have traditionally been based on adaptations of systems used for processing materials such as metal or wood (Brown, James, Purnell, & Swain, 2000). Developments have been empirical and in an environment of commercial competitiveness, the sharing and publication of knowledge and fundamental science has been limited. In the meat industry, cutting is known to have a direct effect on profitability. Cevger, Sariozkan, & Guler (2003) showed that cutting broilers into joints could increase the profits of a poultry plant by up to 15.6% and there was an improvement of almost 2% when manual cutting was replaced by a machine operation.

Literature searches for information on cutting forces, which could be used for design or optimisation, have revealed few published data. As stated by McGorry, Dowd, & Dempsey (2003), even for hand cutting operations 'The force exposure associated with meat cutting operations and the effect of knife sharpness on performance and productivity have not been well documented'. The same authors developed specialised hardware which allowed them to measure peak cutting moments of up to 17.2 Nm in manual lamb shoulder boning.

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0260-8774/$ - see front matter
doi:10.1016/j.jfoodeng.2004.09.022

To develop optimal cutting and slicing systems, data are required on cutting forces for different food types and how they vary with such factors as cutting temperature, speed, type of cutting device e.g. blade profile and edge angle. King (1999) measured the forces, and hence fracture energies, required to cut frozen meat. A knife oscillating in a slicing action was used to cut horse *M. semimembranosus* and *M. longissimus dorsi* over a range of temperatures (−1.5 °C to −30 °C) and vibration frequencies (0–1000 Hz). The blade required less force to cut when slicing than when not slicing; the decrease in force was proportional to the velocity of the slicing motion. These data can be applied to cutting and dicing operations with frozen meat. However, many meat cutting operations take place at temperatures above the initial freezing point of −1.5 °C.

Cheese, bacon and beef are three common foods that are cut and sliced at many times from production to consumption. This paper details the construction of a simple apparatus for cutting force measurement and presents cutting force data for cheese, bacon and beef. The temperatures investigated cover most of the range of interest for industrial processing.

2. Materials and methods

2.1. Food products

Three products were selected for the measurements:

- cheese (mature cheddar sourced from a single local manufacturer),
- beef (cut from lean muscles from topside primals sourced from an on-site abattoir),
- bacon (cut from back joints sourced from a single commercial supplier).

2.2. Sample preparation and fixturing

Samples of each product were band-sawed or manually cut to fit into rectangular section plastic holders of inside dimensions 110 mm long × 50 mm wide × 48 mm high. The holders fitted tightly into a slightly larger, rectangular supporting socket mounted on a support fixture. Narrow slots in the sides of the socket and holder allowed the passage of the blade for the trials (Fig. 1). This method of fixturing provided both restraint for the samples and ensured that they had repeatable dimensions to an accuracy of approximately ±1 mm.

Once cut to size and placed in holders, all the samples were wrapped to avoid moisture loss and conditioned to their required cutting temperatures in a refrigerated chamber adjacent to the experimental cutting rig. For each cutting trial, a sample was removed from the chamber, positioned and immediately cut to minimise any temperature gain. The centre temperatures of three samples in each test group (food–temperature–speed combination) were measured before and after cutting and friction force measurement using a handheld temperature probe (T2006, Digitron) to check that no appreciable sample warming had occurred.

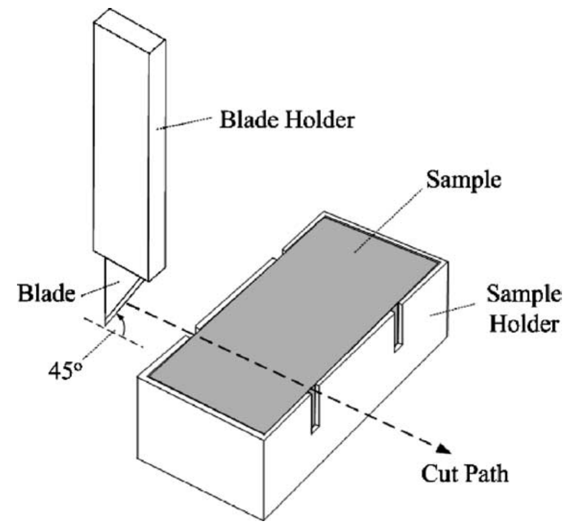

Fig. 1. Schematic of product, holders, blade and cut path.

2.3. Equipment

The cutting tool (Stanley heavy duty trimming blade type 1992) was held in a non-retractable knife handle, modified slightly to allow rigid attachment to an instrumented support plate. The support plate was mounted on a horizontal traverse platform driven by a ballscrew rotated at controlled speeds by an electric motor (M42004-01A-200, AEG). This allowed fixed and repeatable speeds of cutting. For each parameter combination, a new blade was chosen at random from a single batch of blades to minimise blunting from repeated cutting.

The relative positions of the product holders and the blade were set to give a constant cut depth of 16 mm vertically into the sample, i.e. not through the full thickness of the sample. This resulted in a cut area of 16 mm deep by 50 mm long = 800 mm^2. Cutter position was recorded using the output from a draw-wire sensor (WDS-1000-P60-CR-P, Micro Epsilon).

The edge of the blade was orientated at 45° to the feed direction (Fig. 1) to minimise any build-up of force before the blade entered the sample, and give a more 'steady-state' cutting force through the sample. This resulted in horizontal and vertical force components, which were measured through the instrumented support plate using a configuration of four strain gauges. The strain gauge signals were conditioned (2120A, 2110B, Measurements Group Inc.) and recorded at a frequency