COMMUNICATION TO THE EDITOR

A Measure of Fracture Toughness of Bread Crumb

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Dear Editor:

Crumb strength, as an attribute of breadmaking flour quality, is virtually unstudied. Over 50 years ago, Platt and Powers (1940) observed that although much work had been devoted to measurements of the physical properties of doughs, studies of the physical properties of the finished baked product were more limited. This observation has validity even today, despite the importance of the physical properties of the bread to both the baker and the consumer in their assessment of the quality of the baked product (Lasztity 1980, Nussinovitch et al 1992). In the case of bread crumb strength and related tearing phenomena, product quality relates to coherence of the crumb when it is subjected to the shear stresses that are associated with the application of food spreads. Our hypothesis was that because tearing is a fracture phenomenon, the likelihood of tears developing in the bread crumb could be quantified by measuring the fracture resistance of the crumb. Because assumptions on elasticity, linearity, infinitesimal strain, etc., are evidently not feasible in large deformation studies of bread crumb (Lasztity 1980), the standard fracture mechanics analysis chosen was the generalized fracture mechanics theorem of Andrews (1974). Other measures of fracture resistance are available (see, for example, Atkins and Mai [1985, chapters 2 and 4]); these could also be applied to bread crumb studies.

Straight-grade flours were milled from wheat of the Canada Western Red Spring (CWRS) class and the Canada Western Extra Strong (CWES) class. The flour protein contents were 12.9 and 12.2% (14% mb) for CWRS and CWES, respectively. CWRS flour acted as the control, while CWES flour was selected because it possesses very strong dough mixing properties (Bushuk 1980, Sapirstein and Fu 1996), which may be especially useful in frozen dough manufacture (Inoue and Bushuk 1992, Anon 1995). However, to date, there have been no quantitative measurements in SI units of the physical properties of the bread crumb made from CWES flour.

Loaves (560 g) of white pan bread were prepared by a commercial no-time process used at the Canadian International Grains Institute (Winnipeg, MB). Two loaves of CWRS and CWES bread were baked on four separate days. Loaves were sliced longitudinally (Persaud et al 1990) to obtain six internal slices 22–24 cm in length. The dimensions of the specimen tested were thus 20-cm gage length by 5-cm width, to conform with the tensile test specifications of ASTM E8 (ASTM 1993) to ensure that axial tensile stresses were uniformly distributed throughout the gage length of the specimen. Specimens were placed in sealed plastic bags and allowed to equilibrate overnight. The thicknesses of slices were measured to 0.5 mm. Edge cracks of length 0 (unnotched), 15, 25, 35, and 45 mm were cut into specimens at the midpoint of their longitudinal axis using a trimming blade in a sawing action to prevent crumb compression. Specimens were attached by a diamond-shaped four-pin fixture to a TA.XT2 Texture Analyzer and subjected to tensile loading at a rate of 0.1 mm sec^{-1} (nominal strain rate of 5×10^{-4} sec^{-1}) until failure. Fracture toughness, as defined by the critical apparent energy release rate (Andrews 1974, Andrews and Bhatty 1982), was determined according to the procedure of Fahloul and Scanlon (1996).

Figure 1 shows the mean stress-strain curves calculated from the load-deflection data and the initial specimen dimensions. It

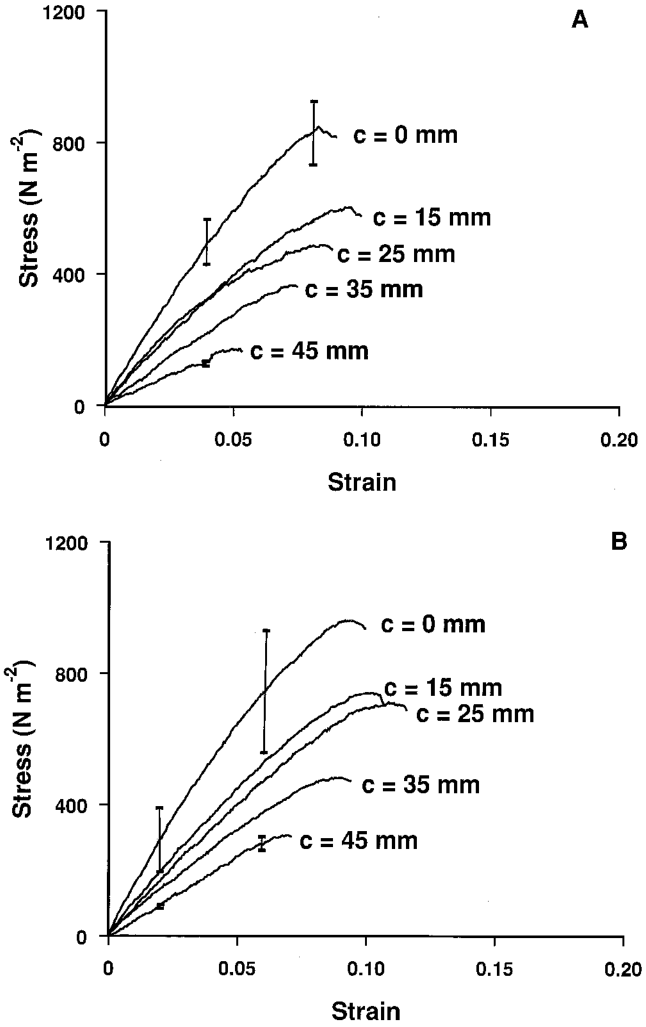

Fig. 1. Mean (n = 8) stress-strain curves for bread crumb with various crack (c) lengths. **A,** Bread made from Canada Western Red Spring (CWRS) flour. **B,** Bread made from Canada Western Extra Strong (CWES) flour. Error bars represent standard error.

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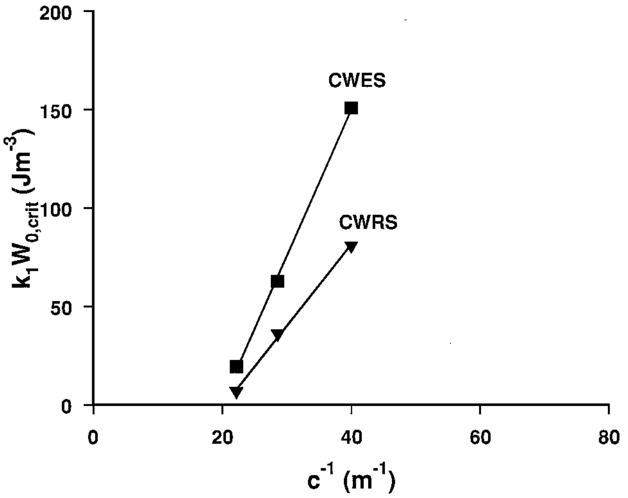

Fig. 2. Plot of total input energy at crack propagation ($k_1W_{0,crit}$) vs. the reciprocal of crack length (c^{-1}). CWRS = Canada Western Red Spring. CWES = Canada Western Extra Strong.

can be seen that generally the stiffness and strength of bread crumb decline with increase in crack length. This is true for bread from both wheat classes and is in line with similar studies on other materials (Atkins and Mai 1985).

Figure 2 shows the last step (Andrews 1974, Andrews and Bhatty 1982, Fahloul and Scanlon 1996) in the calculation of the critical apparent energy release rate: its determination from the slope of the line. Only three points are shown for bread crumb made from each wheat type, because the point associated with the 15-mm crack length has been dropped from the analysis. The justification for this omission relates to the inability to achieve a zero crack tip radius in a cellular material such as bread (Lasztity 1980, Keetels et al 1996). Its anomalous effect on the energy required to propagate a crack of small initial length will be fully discussed in an article to follow. The value of critical apparent energy release rate derived from Fig. 2 is 4.1 J m^{-2} for bread made from CWRS flour and 7.4 J m^{-2} for bread made from CWES flour. This result provides, for the first time, objective and quantitative evidence that bread produced from a stronger dough mixing flour has a more coherent bread crumb that resists tears better than bread derived from relatively weaker wheats.

In conclusion, this communication demonstrates that it is possible to measure the fracture properties of bread crumb in SI units using the critical apparent energy release rate as defined by the generalized fracture mechanics theorem (Andrews 1974). In this way, the critical apparent energy release rate may be an appropriate parameter for investigating the effects of variation in formulation and processing conditions in breadmaking, in much the same way that another fracture toughness measurement, the J-integral, is used to characterize the performance of metallic materials (Clarke et al 1980).

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