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BRUISE RESISTANCE COEFFICIENT AND BRUISE SENSITIVITY OF APPLES AND CHERRIES*

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A b s t r a c t. Bruise Resistance Coefficient (BRC) and Bruise Sensitivity (BS) of stored apples and raw cherries were studied by the quasi-static compression of simple fruits between two plates. The results obtained show that both parameters depend on the extent of compression. For the lowest deformations they were zero. Starting from some characteristic values of the absorbed energy and/or the work of loading the BRC and the BS increased with increasing absorbed energy and the work of loading, respectively. This behaviour was observed mainly for 8 % deformation of apples. For higher deformations (up to the 30 % in the case of cherries) the BRC and/or BS rather decreased with an increasing extent of compression. The initial characteric values of the absorbed energy and the work of loading from which both the BRC and BS increased with the increasing extent of deformation seems to be connected with a characteristic value of the relative absorbed energy for which common value of 0.52 for both apples and the cherries was observed.

K e y w o r d s: fruits, bruising, compression, bruise volume, absorbed energy, hysteresis losses

INTRODUCTION

Fruit bruising is one of the most important factors limiting the mechanisation and automation in harvesting, sorting and transport of apple fruits. Dark spots on the fruit surface are due to previous mechanical contacts of the fruit with other bodies. Loading the fruit can be very variable, ranging from static to dynamic [10,13, 15]. Bruise extent is usually described in terms of bruise volume. Studman [14] lists fourteen factors affecting apple bruising, but the role of some of them is slightly controversial. The most important bruise factor in every case is loading which is usually expressed in terms of loading or absorbed energy [5].

Holt and Schoorl [5] originally described the relation between bruise volume and absorbed energy as a simple linear function where the constant is equal to zero and the slope is called the Bruise Resistance Coefficient (BRC). Other factors affecting apple bruising may be reflected in BRC. This very fruitful yet contra-versial idea was used by Holt and Schoorl [6,7], and others, e.g., Brusewitz and Bartsch [4] and Kamp and Nissen [11]. BRC is a term that increases when bruise resistance decreases, or when bruise volume increases. The proportional character of the relation between the bruise volume and the absorbed energy, does not enable the undamaging level of loading to be defined. Similarly, as BRC the Bruise Sensitivity (BS) is defined as a ratio of bruise volume and loading energy [11].

In this paper the relations between bruise volume and the absorbed energy (BRC) and bruise volume and loading energy (BS) of two apple varieties and two varieties of cherries

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after their bruising were studied by quasi-static loading [10] up to a definite strain with the aim of obtaining more information on BRC at different deformation extents. Freshly harvested (apple and cherry) as well as stored (apple) fruits were used for this purpose.

MATERIALS AND METHODS

Apple fruits were harvested in the production orchard of the agricultural company Caslav at Sukov in Eastern Bohemia on September 22. Thirty defect free fruits were selected from each variety and prepared for the first test without any cooling on September 25. Other harvested fruits were put into 350 kg storage boxes and transported to a warehouse, and stored either at 2-3°C (Spartan) or 0°C (Golden Delicious). Cherry fruits were harvested in the experimental orchards of the Research Breeding Institute at Holovousy at normal harvest time (June12, 1995). The fruits were transported in plastic bags to the Prague laboratory and tested the same day. Table 1 summarises the tested varieties and also gives some of their characteristics.

Thirty defect free fruits were selected from each variety for every test. The fruit diameter was determined directly at three points of fruit equator. The fruits were compressed between two plates (Fig. 1, see also [2]) at a deformation rate of 0.5 mm s^{-1} (apples) or 0.167 mm s^{-1} (cherries) using a universal testing machine. The maximum compression strain ε_T, (the maximum compression deformation divided by the initial diameter of the fruit) was about 8 % for apples and 10 %, 20 %, and 30 % for cherries. After compression to a predetermined strain, the unloading was carried out at the same but reversed strain rate.

Table 1. Basic characteristics of the tested fruits (30 fruits per test)

Variety	Storage conditions	Date of experiments	Fruit diameter	Symbol
		Apples		
Golden Delicious	Before storage	25.09	69.0±0.6	GA1
	Cold storage 0°C	16.10	63.6±0.5	GA2
		14.12	64.3±0.5	GA3
		29.01	62.0±0.4	GA4
		26.02	58.9±0.4	GA5
		28.03	62.0±0.3	GA6
		15.04	60.0±0.3	GA7
		02.05	59.3±0.5	GA8
	Cold storage 0°C with Biofresh	29.01	66.5±0.6	GB4
		26.02	63.2±0.5	GB5
		28.03	64.7±0.3	GB6
		15.04	63.7±0.3	GB7
		02.05	66.5±0.5	GB8
Spartan	Before storage	25.09	65.2±0.6	SA1
	Cold storage 2°C	16.10	65.9±0.4	SA2
		14.12	69.2±0.6	SA3
		29.01	63.1±0.4	SA4
		26.02	62.5±0.5	SA5
		28.03	64.8±0.3	SA6
	Cold storage 2°C with Biofresh	29.01	69.8±0.7	SB4
		26.02	65.3±0.6	SB5
		28.03	65.7±0.3	SB6
		Cherries		
Kordia	Fresh	12.06	7.76±0.11	KOR
Sam	Fresh	12.06	6.22±0.78	SAM

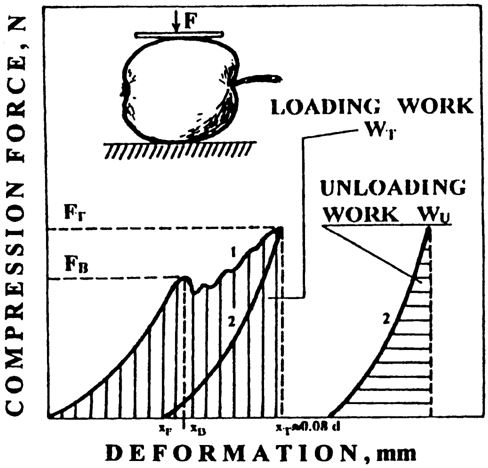

Fig. 1. Schematic representation of the compression test of fruit (apple fruit is drawn as an example) between two plates. It consists of two parts: loading of the fruit (1) at a constant strain rate up to the total compression deformation x_T, followed by unloading at the same but reversed strain rate (2). The bioyield point (F_B and x_B) is shown. Areas expressing the total work of loading (W_T) and uloading work (W_U) are also marked in the figure. The unloading part of the curve is repeated separately to the left.

Every loading-unloading test yielded a force-deformation curve of the characteristic shape shown in Fig. 1. These force deformation data were entered into a computer. The force corresponding to the maximum compression was denoted as F_T (total force). The area between the loading curve and the deformation axis (see Fig. 1) represents the total work of loading, W_T. Similarly, the area between the unloading curve and the deformation axis represents the unloading work, W_U, i.e., the part of the total work of loading that had not dissipated in the course of loading. The difference between W_T and W_U is ΔW, the energy dissipated in the course of the loading-unloading test, also referred to as the absorbed energy.

The deformed fruits were left on the table in the laboratory at room temperature (20-30^0 C) for about 24 h. During this interval the colour of the bruised parts of the fruit flesh changed from the original to brown [5]. The fruits were then cut in the middle of the two bruised spots and the diameters and depths of the spots were measured. These were used to calculate the bruise volume based on the formula given by Mohsenin [12] and used for apples by Holt and Schoorl [5].

RESULTS AND DISCUSSION

The mean values and standard errors of the measured quantities are given in Table 2. The bruise resistance coefficient (BRC) is given under Holt and Schoorl's ratio expression [5] as a ratio of the bruise volume to the absorbed energy. Also the bruise sensitivity (BS) was calculated in the ratio form, i.e., as a ratio of the bruise volume to the corresponding total work of loading. The definition of BRC and BS is based on the nearly proportional character of the experimental relations V-ΔW and/or V-W_T that have been observed repeatedly for apples [1,4-9] and also for cherries (Fig. 2). But some important deviations between the regression line and the experimental points for cherries can be observed in Fig. 2 even if they are partly masked by the usual statistical dispersion. For the lowest values of the absorbed energy no bruise of the deformed fruits were observed. The first small bruise spots appeared at ΔW~2 mJ (Kordia) or ~5 mJ (Sam). Only for the highest values of the absorbed energies (higher than ~ 20 mJ) the experimental points are usually well described by the corresponding regression lines. The bruise spots on apples were observed only for absorbed energies higher than ~60 mJ (Table 2, see also [1]). Similar deviations between the regression line and the experimental points were also observed for V-BS relation. The first bruises were observed at the

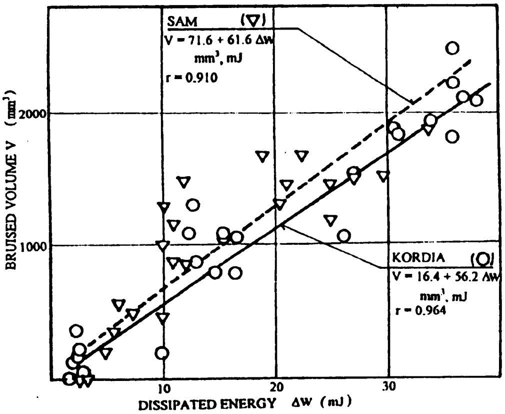

Fig. 2. The bruise volume of the tested cherry fruits plotted against the energy dissipated in the compression test (absorbed energy).

Table 2. Test parameters (MV- mean value, SE- standard error). The additional numbers at symbols for cherries (KOR and SAM) denotes the deformation extent (01-10 %, 02-20 %, 03- 30 % deformation)

Symbol	Work of loading W_T (J)		Absorbed energy ΔW (J)		Bruise volume V (cm^3)		BRC (ratio) (cm^3 J^{-1})		BS (ratio) (cm^3 J^{-1})	
	MV	SE	MV	SE	MV	SE	MV	SE	MV	SE
GA1	0.672	0.024	0.423	0.011	3.025	0.151	7.08	0.25	4.50	0.19
GA2	0.509	0.023	0.299	0.009	3.132	0.136	13.70	0.96	7.84	0.48
GA3	0.264	0.012	0.156	0.070	0.760	0.097	4.17	0.50	2.55	0.31
GA4	0.252	0.008	0.155	0.004	1.140	0.075	7.16	0.44	4.44	0.28
GA5	0.202	0.008	0.123	0.004	0.385	0.055	2.93	0.36	1.81	0.23
GA6	0.176	0.009	0.104	0.005	0.366	0.065	2.93	0.45	1.53	0.23
GA7	0.145	0.010	0.087	0.004	0.237	0.052	2.12	0.43	1.31	0.27
GA8	0.130	0.008	0.082	0.005	0.187	0.041	1.84	0.36	1.46	0.31
GB4	0.234	0.016	0.135	0.006	0.771	0.087	5.24	0.50	3.06	0.30
GB5	0.153	0.012	0.091	0.005	0.228	0.049	2.10	0.39	1.26	0.24
GB6	0.153	0.010	0.086	0.005	0.251	0.054	2.33	0.43	1.10	0.21
GB7	0.098	0.006	0.057	0.003	0.006	0.003	0.08	0.04	0.05	0.02
GB8	0.141	0.010	0.082	0.005	0.155	0.059	1.28	0.45	0.78	0.27
SA1	0.644	0.019	0.398	0.008	2.593	0.084	6.48	0.14	4.02	0.11
SA2	0.417	0.014	0.275	0.007	1.727	0.143	6.26	0.55	4.12	0.35
SA3	0.428	0.015	0.307	0.008	5.010	0.342	16.30	1.06	11.72	0.77
SA4	0.294	0.009	0.209	0.005	2.030	0.073	9.69	0.28	6.67	0.15
SA5	0.280	0.007	0.199	0.004	1.971	0.072	9.92	0.34	7.03	0.23
SA6	0.300	0.007	0.215	0.004	2.645	0.057	12.36	0.24	8.86	0.19
SB4	0.355	0.013	0.249	0.007	3.260	0.150	13.00	0.40	9.17	0.31
SB5	0.314	0.010	0.222	0.006	2.286	0.104	10.32	0.44	7.31	0.30
SB6	0.305	0.011	0.214	0.006	2.741	0.114	12.77	0.39	8.97	0.30
KOR01	0.00490	0.00016	0.00279	0.00012	0.0786	0.0139	28.00	11.20	17.80	7.20
KOR02	0.01730	0.00070	0.01340	0.00070	0.8690	0.0360	64.60	8.00	50.40	6.00
KOR03	0.04360	0.00150	0.03760	0.00140	2.0700	0.0270	56.60	3.40	48.80	1.80
SAM01	0.00308	0.00011	0.00202	0.00008	0.0372	0.0095	18.40	10.00	12.00	6.40
SAM02	0.01170	0.00070	0.09200	0.00006	0.8560	0.0044	93.40	15.00	73.20	11.80
SAM03	0.02810	0.00100	0.02440	0.00008	1.5150	0.0021	62.00	3.80	54.00	3.40

following values of the work of loading: ~ 4 mJ (Kordia), ~ 6 mJ (Sam), and ~ 100 mJ (apples).

The observed deviations show that BRC and BS are not constant. They are zero for very low compression extents in apples and after reaching some critical values of the absorbed energy (or total work of loading) BRC and BS vary generally. For description of the BRC- and BS-changes in relation to the compression extent the generalised power function was used in this paper. The tested specimens were divided into two groups. The first contained all the tested apple fruits with exclusion of the two first measurements (GA1, GA2, SA1 and SA2 - see also [1]) and the second containing all the cherry specimens (Kordia, Sam). The bruise volume for the first group were well approximated by the generalised power function of the absorbed energy (Fig. 3) and the same function with different parameters can be used for the approximation of results for the second group (Fig. 3). Moreover, the same operations can be also done for bruise volume and the total work of loading.

The generalised power function makes it possible to describe some of the observed non-linear parts in V-ΔW and V-W_T relations. The slope of this curve is not constant as in the case of linear function. It means the variable character of BRC and similarly of BS expressed in the slope form [3] has to be respected in this case. Figure 4 represents graphs of the first derivatives of the functions given in Fig. 3 and these curves have to be understood as graphs of BRC in the slope form plotted against the absorbed energy. Figure 4 seems to be strange: the BRC

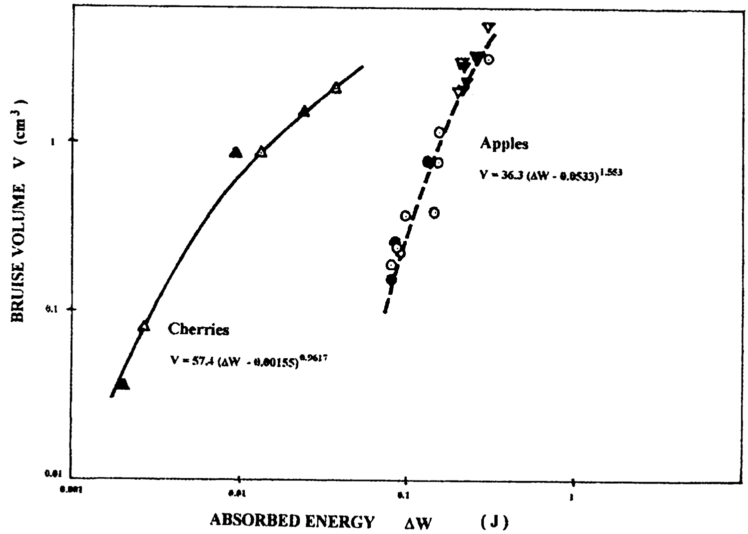

Fig. 3. The bruise volume of the tested samples plotted against the absorbed energy in logarithmic scale. Every point represents mean value of the tested sample (10 specimens for cherries and 30 specimens for apples).

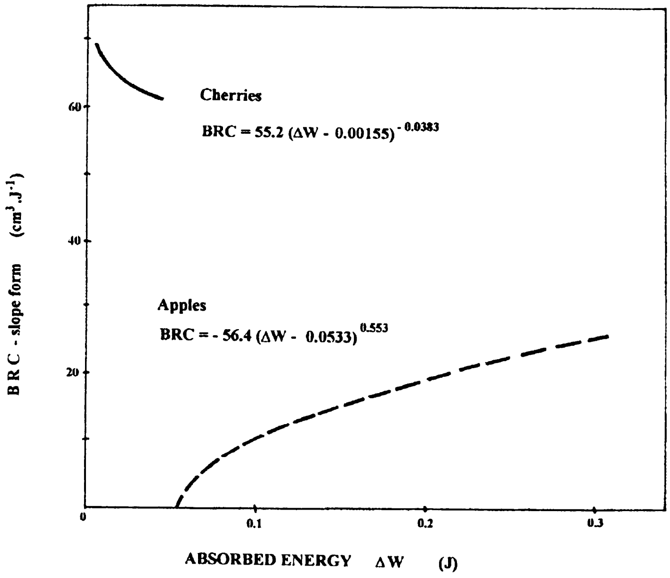

Fig. 4. The Bruise Resistance Coefficient (BRC) evaluated as a slope of the experimental curves in Fig. 3. It is expressed as a first derivative of the functions used to approximation of the experimental results in that figure.

values decrease with increasing absorbed energy for cherries and increase with the same change of the absorbed energy for apples. The strange behaviour of the computed BRC and BS values result from our model equation (the generalised power function between ΔW and V in Fig. 3), i.e., the function without any point of inflexion. The real V-ΔW curve for cherries has to have at least one point of inflexion (Fig. 2), which divides the real curve into two above mentioned parts: the first with the slope increasing from zero to the maximum value and the other with a constant or decreasing slope. For cherries, the generalised power function used in Fig. 3 stresses only the experimental points behind the point of inflection and the resulting curve has a decreasing slope. For apples the part behind the point of inflexion misses, if exists any, so that only the experimental points before the point of inflection have to be respected by the generalised power function. When the experimental results were limited to those lying before the point of inflexion in the case of cherries, i.e., for values ΔW = 2-8 mJ (Kordia) and ΔW = 5-8 mJ (Sam), the BRC-ΔW function increasing aproximately in a linear way and BRC-ΔW function increasing approximately quadratic way were obtained for Kordia and Sam, respectively. It means the generalized power functions used for V-ΔW relations before the point of inflexion in the case of cherries, is very similar to that used in the case of apples (Fig. 4). It is very difficult to study some more sophisticated V-ΔW functions on the basis of the presented results only. More exact and more complex measurements should be performed for this purpose.

Figure 4 shows that the absorbed energy cannot be used as a controlling parameter of BRC for fruits of different origin. A more suitable parameter should be the relative absorbed energy (Fig. 5), that could be used at least for the determination of the initial point of bruising. For both the cherries and the apples the fruit bruising began at approximately the same level of relative absorbed energy ($\approx$ 0.52).

CONCLUSIONS

The BRC and BS cannot be understood as the fruit constants independent of the bruise extent. The bruising of cherries and apples begins at some positive values of the absorbed energy (total work of loading) depending on the tested product. Then before reaching some deformation extent both the BRC and BS increase with the increasing absorbed energy (or total work of loading) and there are some indications of decrease of these parameters for higher increasing values of ΔW and W_T (at least for the cherries). The relative absorbed energy seems to be the factor that exerts some controlling role in the bruising of fruits of different origins.

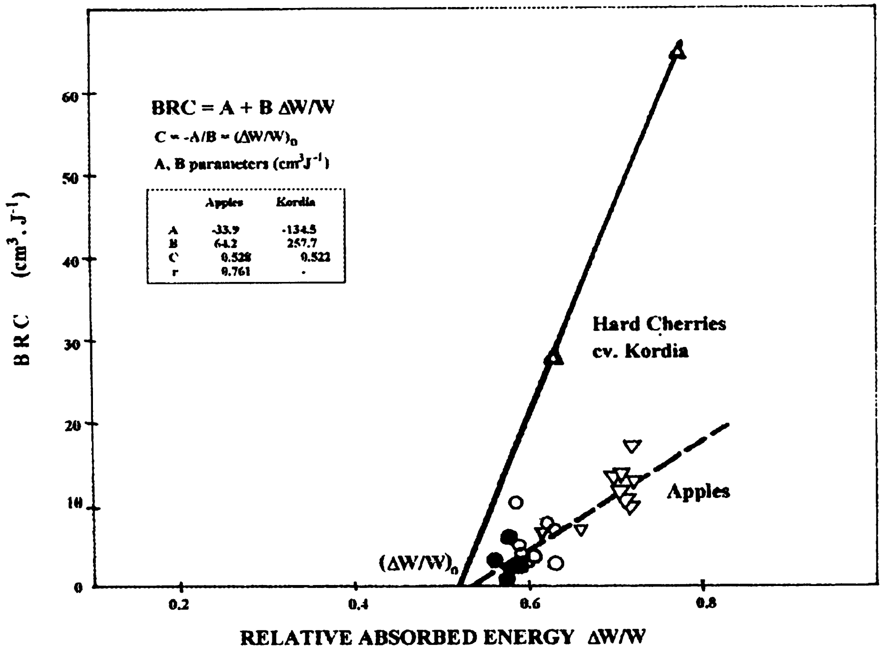

Fig. 5. The Bruise Resistance Coefficient (BRC) in the ratio form plotted against the relative absorbed energy.

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