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CLIMATIC CONDITIONS VS. HYGROSTABILITY AND STRENGTH PROPERTIES OF CORRUGATED BOARD

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SYNOPSIS. The paper discussed the effect of the air relative humidity on the development of dimensional hygrostability of corrugated board as well as on its selected strength properties. The degree of deformation under the influence of moisture content was determined as well as the resistance of individual papers and the entire 3- and 5-layer corrugated board to the burst, ETC, FTC and BTC (this measurement referred to boxes made from board).

KEY WORDS: water vapour, pulp, paper products, fibres

INTRODUCTION

Paper industry is among the most advanced branches of chemical wood technology. From year to year demand for paper articles still grow up. It can be attributed, among others, to the renewable raw material base, relatively low price and versatility of their functional properties (Przybysz and Przybysz 2002, Tarnawski 1999).

In order to assess the quality of paper articles, over sixty of their properties are assessed which can be divided into the following general groups: structural-dimensional, strength, visual, **hydrophilic-hydrophobic**, protective, dielectric, chemical and special. The hydrophilic-hydrophobic properties may, in turn, be divided into: hydrostability and hygrostability.

This study focuses on issues associated with the dimensional hygrostability of paper products. This property characterizes the predisposition of paper articles towards deformation (dimension changes of paper sheets in the x-y plane) as a result of changes in air humidity.

In industrial practice, dimensional stability (in graphic arts also referred to as dimensional consistency) is determined by the measurement of paper elongation and shrinkage following changes of the air relative humidity from 35% to 70% and from 70% back to 35% at the relative air temperature of 23°C. The obtained change of dimensions is referred to the initial value and expressed in percent (Przybysz 1997).

Factors influencing the dimensional stability of paper products comprise primarily:

– The composition of the paper stock (its origin, method employed to obtain it, chemical composition, anisotropy, two-sidedness as well as the content of: glue, fillers and other chemical additives),

– Conditions in which paper is manufactured (the most important are: temperature and drying method – with or without shrinkage),

– Paper air-conditioning and storage conditions.

As in the case of wood and wood derived materials, also in the case of paper the main factor which causes its deformation is the water vapour absorbed by these products. Changes occurring in the dimensions of fibres in these articles are transferred into their overall structure.

The dimensional hygrostability exerts a significant influence on the workability and usability of paper products.

Inappropriate dimensional stability leads to sheet or reel waviness which hinders or can even make it completely impossible for the paper processing machines to work properly because of frequent machine breaks. Generally speaking, products characterized by inadequate dimensional stability reduce the output of the processing facilities and lead to the development of excessive amounts of rejects.

Apart from the worsening of workability, unsatisfactory dimensional stability of paper articles exerts a deteriorating impact on the quality of the products obtained from such papers.

Packaging made from such papers undergoes excessive deformation under the influence of changes in the air humidity.

In the case of printings, variations in the air humidity may result in colour mismatching or rippling of the paper in books.

Corrugated board is a packaging material consisting of flat and corrugated layers of paper or cardboard arranged alternately and glued together. Depending on the number of the applied layers, the following types of corrugated boards are distinguished: two-, three-, four-, five- and seven-layered boards (Modzelewska and Przybysz 2003).

Undulated layers of the corrugated board, so called fluting, cause that this material is characterized by good absorption properties and cartons made from it provide satisfactory protection for packed products against mechanical damage.

One of the disadvantages of the corrugated board is its relatively poor resistance to the action of atmospheric factors. When wet, the corrugated boards lose their rigidity and absorbing properties (Jakowski 2005).

The flute height affects the properties of the corrugated board. The higher the flute, the better absorption properties the finished product will have and the carton made from it will be characterized by greater rigidity. However, as the flute height increases, so does the material consumption of the cardboard. For instance, cardboard with a high flute A is characterized by good absorption properties and guarantees a relatively high rigidity of the box construction and resistance to pressure when piling up cartons into stacks (BCT). The use of this type of cardboard is still recommended but only in situations when goods highly sensitive to mechanical damage (e.g. glass) are packaged.

The quality of corrugated paper is strongly affected by the material employed for its manufacture, that is to say papers and cardboards from which flat and corrugated layers are made as well as the applied glues. The quality of the gluing of individual layers is also important.

The principal material from which the flat layers of the corrugated boards are made are cardboards from sulphate pulp of the *kraftliner* type. In recent years, for aesthetic and advertising reasons, elastic papers as well as bleached and coated papers and cardboards have been used for flat external layers. At the same time, economic and ecologic considerations resulted recently in a distinct increase of the application of flat layers which contain secondary raw materials (*testliner*). The paper used for the corrugated layers is usually manufactured from semi-chemical pulps derived from broad-leaved wood, currently also with the addition of ground wood pulp or pulped waste paper, which has a positive influence on the price and ecological evaluation of the final product (JAKOWSKI 2005, TARNAWSKI 2003). However, it should be remembered that the excessive quantities of waste paper can reduce mechanical properties of the manufactured cardboard and can also increase the tendency for strains and deformations (WANDELT 1999, SUREWICZ 1971).

The strength and absorption properties of corrugated boards depend on the combination of various layers and properties of the individual layers. Moreover, the quality of various kinds of overprints placed on the external flat layer and, hence, the overall appearance as well as the promotional-advertising value depends on the properties of this very layer.

The main impulse to undertake investigations on the dimensional hygrostability of paper products, in particular on the impact of atmospheric conditions on selected functional properties of the corrugated board came from the introduction into the processing and graphic arts industries of new, computerized and highly efficient technological lines. The basic precondition for the proper operation of such lines is the use of paper materials of precisely defined and unchangeable quality characteristics. In addition, as mentioned in the introduction, in the case of corrugated boards which are extremely absorptive, their resistance to wetting is exceptionally important, since this property exerts a significant influence on the strength, protective and absorption properties not only of the cardboards themselves but also of boxes manufactured from them.

The results presented in this study constitute part of a comprehensive research project realised at the Institute of Chemical Wood Technology at the Agricultural University in Poznań.

Papers for the flat layers of the corrugated board form the basic element of this product and it is their properties and quality that influence very strongly the property of the final product – the corrugated board. The shape of the flute as well as the quality of papers used for the corrugated layer and the quality of gluing of individual layers are also very important.

MATERIALS AND PROCEDURES OF INVESTIGTION

The material for investigations comprised papers employed to manufacture corrugated boards as well as corrugated boards and cartons made from them. Experiments were conducted on three- (with A, B and C flute) and five-layer (with BC flute) corrugated boards.

The scope of experiments included the examination of the impact of the air humidity on the following properties of the corrugated board and its components:

– resistance to burst – the bursting strength test BST: for papers in compliance with the standard: PN-ISO 2758, for cardboard: PN-ISO 2759,

– resistance to edge crush – the Edgewise Crush Test (ECT): PN-85/P--50143/06, ISO 3037,

– resistance to flat crush – the Flat Crush Test (FCT): PN-84/P-50143/03, PN-EN 23035,

– box resistance to static compression – Box Compression Test (BCT): PN-ISO 12048.

Measurement of strength properties in the range of relative air humidity 33-98%

The strength indices of the corrugated board: ECT, FCT as well as boards – BCT were carried out using the equipment of the Zwick Company. Measurements were conducted on the air conditioned boards in normal conditions and on the same samples following their air-conditioning in a properly prepared air conditioned chamber at the air relative humidity ranging from 33-96%, time of the air-conditioning process – 24 h.

Determination of the dimensional stability at the change of relative air humidity 30-75%

In laboratory conditions, an English apparatus PATRA is used to ascertain the dimensional stability = deformation of paper. It allows to assess changes in the length and width of the product when changes in the air humidity occur.

The apparatus is made of vessels which are used to obtain air of the required humidity, a membrane pump which pumps the air to plastic pipes fixed to the base of the measuring apparatus and a set of parts which are used to stretch the sample and which allow to record the elongation of samples suspended on a plate. The set of these parts include: fixed articulated bottom clamps, strips assisting the fixing and loading of samples, top clamps, bolts with knurled nuts, micrometers (6) as well as control lamps. The apparatus is designed to analyse samples 10, or 20 cm long and 1.5 cm wide. The Plexiglas pipes constitute the outer protection.

Samples 15 mm wide and 200 mm long cut out from both directions of the paper were prepared for the determinations. On the basis of Table 2 data, the saturated solution of the appropriate salt was prepared in one vessel which was to guarantee to maintain air of the required humidity. The second vessel may serve

Table 1. The employed designations

Papers for the flat layers of the corrugated board, i.e. kraftliners and testliners	Papers for the undulated layers of the corrugated board, so called fluting	Three-layered corrugated boards manufactured in various combinations using the above-mentioned papers	In the case of the five-layer cardboard, the following combinations were applied
KR 200 – two-layer kraftliner of 200 g/m^2	FL 140 – fluting of 140 g/m^2	1 – flute A – BTL^m 130, FL 105, TL^m 125	I – flute BC – TL 140, FL 105, TL^m 140, FL 105, TL^m 140
KR 140 – two-layer kraftliner of 140 g/m^2	FL 127 – fluting of 127 g/m^2	2 – flute A – TL^m 140, FL 105, TL^m 140	II – flute BC – KR 140, FL 105, TL^m 140, FL 105, TL 140
TL 200 – two-layer testliner 200 g/m^2	FL 105 – fluting of 105 g/m^2	3 – flute A – KR 200, FL 105, KR 200	III – flute BC – KR 200, FL 105, TL^m 140, FL 105, KR 140
TL 140 – two-layer testliner 140 g/m^2		4 – flute B – BTL^m 130, FL 105, TL^m 125	
TL^m 125 – two-layer testliner 125 g/m^2 (with the addition of waste paper)		5 – flute B – TL^m 140 , FL 105, TL^m 140	
TL^m 140 – two-layer testliner 140 g/m^2 (with the addition of waste paper)		6 – flute B – KR 200, FL 105, KR 200	
BTL 150 – testliner; two-layered with bleached external layer 150 g/m^2		7 – flute C – BTL^m 130, FL 105, TL^m 125	
BTL^m 130 – testliner; two-layered with bleached external layer 130 g/m^2 (with the addition of waste paper)		8 – flute C – TL^m 140 , FL 105, TL^m 140	
		9 – flute C – KR 200, FL 105, KR 200	

Table 2. Applied solutions of saturated salts and other compounds as well as achieved humidity over solution

The chemical formula	The relative air humidity over solution [%] in temperature 20 ±2°C
P_2O_5	∼ 3
KOH	9
CH_3COOK	22
$MgCl_2$	33
K_2CO_3 (aq.)	44
$Mg(NO_3)_2$ (aq.)	53
$NaNO_3$ (aq.)	65
NaCl (aq.)	76
KCl (aq.)	86
KNO_3 (aq.)	94
H_2O	∼ 98

as a reserve container. In order to place the sample on clamps, the plate together with clamps and the micrometer must be lifted and, after fixing the paper bands, the whole device must be placed in the plastic pipes. Next, each knurled nut is turned in succession until the control light begins to flicker, then the pointer of the micrometer is brought to the "0" position, the housing is mounted and the pump is activated. Following the set time of the measurement (6 h) counted from the moment the equilibrium and the constant air humidity in the bottle and in the apparatus are reached, the knurled nut is set in the initial position again at which the light begins to flash again and the result of measurement is read on the scale of the micrometer.

The results are given with 0.01 mm accuracy as an arithmetic mean calculated separately for the longitudinal and cross section directions or in percent with 0.02% accuracy in accordance with the BN-69-7308-12 standard.

DISCUSSION ON RESEARCH RESULTS

The quality and fibre composition of papers of the same basis weight influenced burst. Papers manufactured from primary raw materials of high quality were characterized by a considerably higher resistance to burst (TL140 = 410 kPa) than papers of the identical basis weight but with an addition of waste paper (TL^m 140 = 360 kPa), it is less than 12%.

It is evident from the research results presented in Table 3 that, in the case of papers air-conditioned in the chamber with increased relative air humidity (above 60%), the resistance of papers to burst decreased by, on average, about 50 kPa. The biggest differences were recorded in the case of: KR 140, TL 140 and TL^m 125; for example, papers of the TL 140, TL^m 140 type air-conditioned in normal conditions reached the burst values of, respectively: 410 kPa and 360 kPa, whereas these values for the same papers air-conditioned in conditions of increased

Table 3. Burst assay results for papers intended for flat layers of the corrugated board

Symbol of the component paper	Value of the burst of the examined papers on flat layers of corrugated bard in [kPa]	
	air conditioned in normal conditions temperature ±23°C, air relative humidity ~ 50%)	at air relative humidity ~ 60-70%
KR 200	900	850
KR 140	700	640
TL 200	600	550
TL 140	410	350
TL^m 125	350	290
TL^m 140	360	315
BTL 150	350	280
BTL^m 130	280	210
FL 140	350	310
FL 127	335	290
FL 105	300	250

humidity were: TL 140 = 350 kPa, TL^m 140 = 315 kPa (difference of relative air humidity is 20 ±2%).

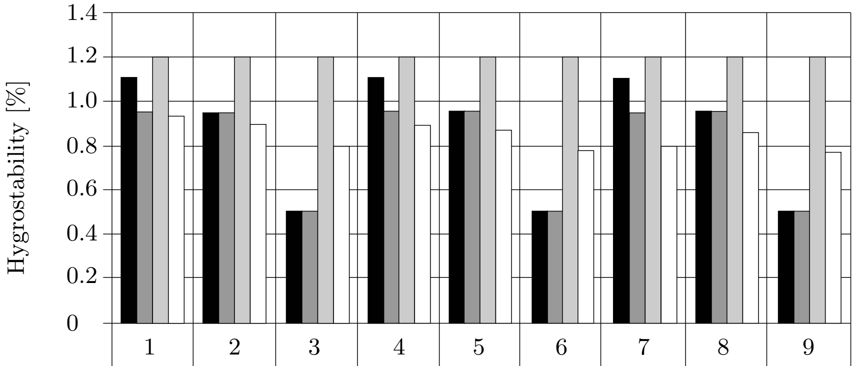
In the group of the examined papers intended for the flat layers of the corrugated board, the worst resistance to burst was found in bleached testliners and this referred both to those air-conditioned in normal conditions and those kept in the elevated air relative humidity. This was associated with the raw material composition of these papers but, first and foremost, with the quality of the external layer of the paper which was subjected to bleaching.

Table 4 shows results of assays of moisture content deformations found in the component papers of the examined corrugated boards, while Figure 1 illustrates this phenomenon additionally as exemplified by a three-layered corrugated board.

It is evident from the presented diagram that fluting, which is responsible for the quality and properties of the corrugated board, in comparison with liners, is the

Table 4. Value of dimensional hygrostability of the component layers of the examined corrugated boards

Symbol of the component paper	Value of dimensional hygrostability of component papers of three- and five-layer corrugated board [%]
KR 200	0.5
KR 140	0.4
TL 200	0.8
TL 140	0.7
TL^m 125	0.75
TL^m 140	0.95
BTL 150	0.98
BTL^m 130	1.1
FL 140	1.35
FL 127	1.29
FL 105	1.2



	1	2	3	4	5	6	7	8	9
liner 1	1.1	0.95	0.5	1.1	0.95	0.5	1.1	0.95	0.5
liner 2	0.95	0.95	0.5	0.95	0.95	0.5	0.95	0.95	0.5
liner 3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
liner 4	0.93	0.9	0.8	0.89	0.87	0.78	0.8	0.86	0.77

Corrugated board: 1, 2, 3 with flute A; 4, 5, 6 with flute B; 7, 8, 9 with flute C

Fig. 1. Moisture content deformation of component papers and the entire 3-layer corrugated board

most sensitive component to changes in the air relative humidity. For example, the moisture content deformation of the entire corrugated board of type 3 with the A flute amounted to 0.8%, while that of the fluting – to 1.2%. This interrelationship was found similar in all of the examined cardboard types.

It can be concluded from the performed experiments that it is the flute component layer that is mainly responsible for the deformation of the examined cardboard. Its high sensitivity to deformations caused by the increase of the air humidity in the interval from 30-70% decreased the quality of the entire three-layered cardboard.

The type of the employed fibrous raw material is also very important. The KR and TL types of papers are characterized by a considerably lower dimensional hygrostability than those manufactured with the addition of the secondary fibres (e.g. FL 140 =1.35%, FL 105 =1.2%, TL^m 125 =0.75%, TL^m 140 =0.95%, BTL^m 130 = 1.1%).

This correlation was found also in the case of the five-layered corrugated boards as shown in Figure 2 and Table 5.

The worst deformations were determined in the fluting (1.2%) despite the fact that the moisture content deformation of the examined five-layered corrugated boards, irrespective of their composition, did not exceed 0.71%. On the basis of the comparison of results of the examined five-layer corrugated boards it can be concluded that the cardboard with the composition designated as III turned out to be the most sensitive to deformations caused by changes in the humidity of the ambient air as its deformation reached 0.71%, while in the remaining cases, these values were: 0.58% in the case of the corrugated board with the composition designated as II and 0.65% – designated as I.

Table 5. Value of the moisture content deformation of component papers and the entire five-layered corrugated board

Type of component paper	Value of moisture content deformation for component papers and five-layer corrugated board with the BC flute [%]		
	corrugated board I	corrugated board II	corrugated board III
liner 1	0.7	0.4	0.5
liner 2	0.95	0.95	0.95
liner 3	0.95	0.7	0.4
fluting 1	1.2	1.2	1.2
fluting 2	1.2	1.2	1.2
corrugated board	0.65	0.58	0.71

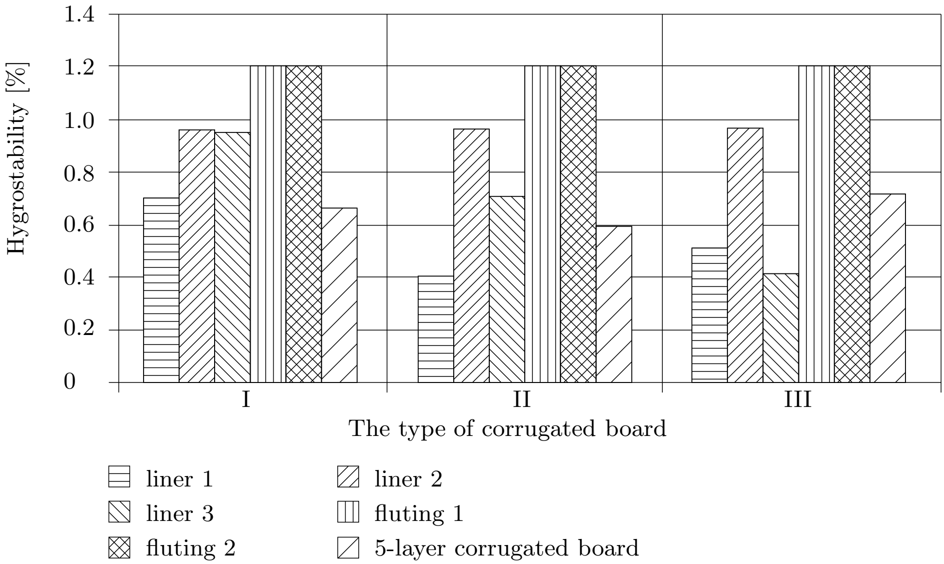


Fig. 2. Moisture content deformation of component papers and the entire 5-layer corrugated board

In order to examine the influence of the air relative humidity on the strength properties of the experimental corrugated board it was subjected to air-conditioning in chambers with controlled humidity and the ECT and FCT were determined. In addition, using the examined cardboard, boxes of various dimensions were made which were then subjected to air-conditioning in changing conditions of relative air humidity. They were then used to determine how this influenced their compression strength (determination of BCT).

Table 6 shows ETC values for cardboards with different flutes. In addition, Figure 3 presents results of measurements of three-layered corrugated boards with the B and C flute as well as of five-layered corrugated boards with the BC flute.

Together with the increase in the air relative humidity the resistance of cardboards to the edge crush (ECT) decreased. In the case of the cardboard with the B flute, the observed decline was by about 2 N/m, with the C flute – by 3 N/m,

Table 6. ECT assay results of the corrugated board in relation to the air-conditioning conditions

Relative air humidity [%]	ECT result [N/m]		
	flute B	flute C	flute BC
33	5.19	5.57	7.96
39	–	4.95	7.85
46	4.83	5.35	7.85
50	4.88	5.24	7.83
70	4.7	4.76	7.13
93	2.82	2.94	4.2

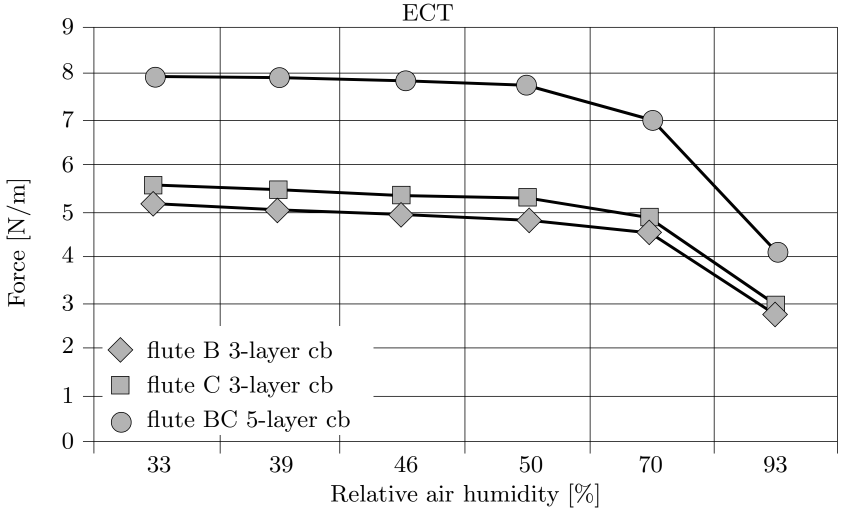


Fig. 3. Effect of the air relative humidity on the ECT of the corrugated board

Table 7. FCT assay results of the corrugated board in relation to the air-conditioning conditions

Relative air humidity [%]	ECT result [N/m]		
	flute B	flute C	flute BC
33	263.75	173	137
39	421.01	169	136.08
46	364	164	133.43
50	339	159.27	131.35
70	221.91	145.03	118.78
93	170.63	94.95	69.62

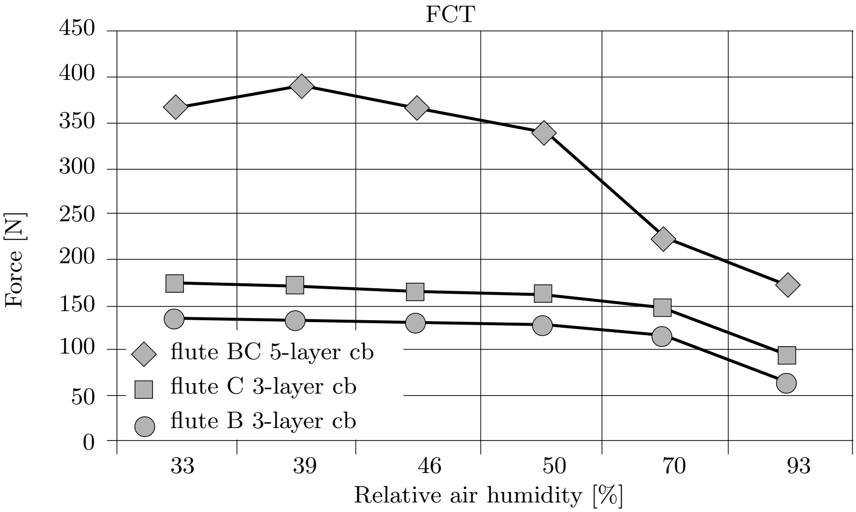


Fig. 4. Effect of the air relative humidity on the ECT for the examined corrugated boards

while for the five-layer cardboard with the BC flute the value of the ECT dropped even by 3.65 N/m.

Similarly to the ECT, also in the case of the flat crush test (FCT), the increased air humidity (above 50%) resulted in the decline of the FCT, both in the case of three- and five-layered cardboards (Table 7 and Fig. 4).

The performed experiments showed that the increase in the ambient air humidity resulted in approximately 50% drop of the resistance in the cardboard flat crush in all the examined cases. The 5-layer corrugated board is considerably more resistant to both ECT and FCT. This is probably the result of its structure (more layers and two types of waves – B and C). Therefore, this may contribute to the slower penetration of moisture deep into its structure which makes it more resistant to both edge and flat crushing.

The most important task of cartons made from corrugated boards is to protect packaged articles against damage. This basic function of boxes changed together with the increase in the air relative humidity. Cartons air-conditioned when the ambient air humidity exceeded 50% dramatically changed their resistance to compression.

This is very well illustrated in Figure 5 for boxes made from the cardboard with the BC flute and measuring: 100/100/100 mm, 200/200/200 mm and 300/300/300 mm. When the humidity of the ambient air was about 100%, boxes made from the examined corrugated board practically disintegrated (Modzelewska and Przybysz 2005). In the case of the resistance of these boxes to static compression (BCT), this resistance decreased by about 1-1.5 kN, irrespective of the type of the examined corrugated board and regardless of the applied flute.

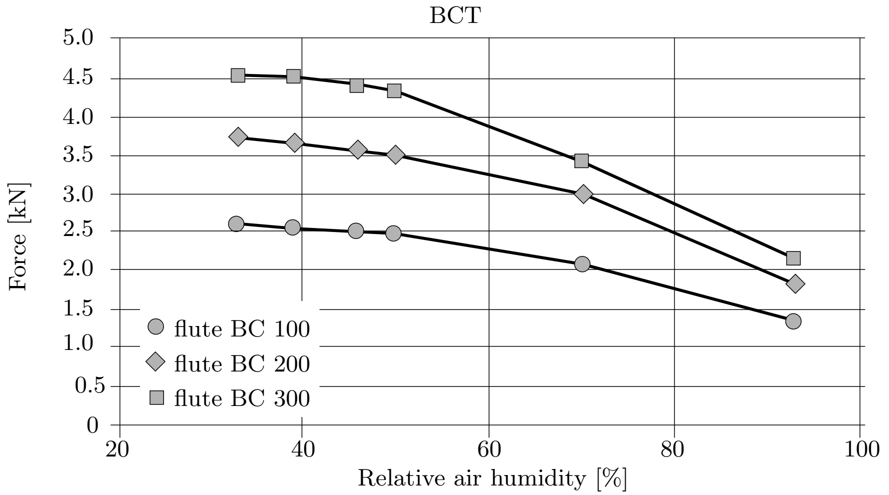


Fig. 5. Effect of the air relative humidity on the BCT value for boxes of different dimensions made from corrugated board

CONCLUSIONS

It is apparent from the above-presented considerations that the resistance of boxes to the crush and of the papers intended for the flat and undulated layers of the corrugated board to burst depend very strongly on: the type of the fibrous pulp used to manufacture paper, the method it is obtained and the paper basis weight. Papers manufactured from primary fibrous raw materials are characterized by higher values of strength indices in comparison with papers obtained from secondary or worse quality fibres. This tendency is also maintained in the case of papers air-conditioned at increased humidity which are exposed to the contact with ambient air of over 60% humidity and, sometimes, reaching 100%.

Generally speaking, the increase of the air relative humidity to over 60% reduces strength parameters of corrugated boards and cartons made from them as confirmed by values of ECT, FCT and BCT. This means that both protective and absorption properties of the corrugated boards decrease.

The best materials to manufacture flat layers and flutes of corrugated boards comprise papers with the lowest possible addition of secondary fibres and of the lowest basis weight. Together with the increase of the flute height and basis weight, the resistance to deformations decreases and, therefore, the moisture content deformations increase.

However, climatic conditions play the most important role. The corrugated board is an exceptionally absorptive material and, therefore, it should be remembered to control both air temperature and humidity, especially during its manufacture, storage and transport.

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