Influence of high grades paper properties on Adhesive Binding Strength in a humid condition

Suzana Pasanec Preprotić, Maja Jakovljević
Faculty of Graphic Arts, The University of Zagreb, HR - 10000 Zagreb

Abstract: *Class book, pocket book, annual book, proceedings book and note book are the reusable paperback products. That is a good reason researching adhesive binding quality when soft bound book is stored on humid conditions. The benefit of paperback form is an easy way of handling the text block during the reading. Also the paperback has mostly required reading for customers' different ages for its low-price and practicality. Uncoated paper mostly takes place in making of text block form including perfect binding technique with HM adhesive. If adhesive binding quality is sufficient, the text block damages almost certainly. This research focuses on understanding of high grades paper properties because adhesive binding strength is only available at paper bindability. The text block volume has consisted of a number of loose leaves and hold together at spine edge with adhesive. Paper bindability can be observed in every aspect paper adherent features, the bounded layers increase in strength if paper properties are suitable for adhesive binding. The hypothesis is that paper property would indicate a reduction in the adhesive binding strength in humid condition. Paperbacks were exposed to moisture-low heat ageing over period of time (ISO 9142). The static tensile stress method (loose leaf pull-test) has been in use. The adhesive joint strength results are compared with a rating of adhesive strength according to FOGRA Nr.71006 guidelines for page pull-test.*

Keywords: *adhesive joint strength, paper properties, text block binding edge*

Introduction

Generally, Paperback is defined as flat back book with a paper cover. It is often made of the loose leaves by cool settings adhesive [1]. Perfect binding method includes securing loose leaves into a solid text block by means of thermoplastic adhesive alone [2]. The loose leaves binding edges are applied with adhesive, loose leaves are fasten firmly together because high grades paper adherend improves adhesive mechanical interlocking [3]. Furthermore, different uncoated high grades papers (wood-free, wood content) are the most commonly used in paperbacks production [4]. High grades paper bindability increase depends on increase of its tensile strength property [5]. The loose leaves binding edges after roughening process directly explains high grades papers adherend characteristics and it's establish adhesive joint strength durability [6–8]. High grades paper structural characteristics affect to its dimensional stability changes in relation to atmosphere relative humidity increasing. Hence, fibers network structure hygroexpansivity mainly causes paper physical properties changes [9]. Paper strain rateCD property increasing occurs due to fibers more expanded in paper lateral (CD) than in longitudinal (MD) direction after ageing. The loose leaves are more extensible in lateral direction [10] through Paperback width, hence paper physical properties determine the adhesive binding strength increasing.

Experimental

The experiment is divided into two parts, in the first part of research two commercial high grades papers with same basic weight, 80 g/m2 were included. The first uncoated paper (N_80) contains

free pulp only and the second bulky paper (V_80) contains mechanical wood pulp more than 10% [11]. The commercial papers name are Amber graphic (N_80) and Munken print White 15 (V_80). Selected papers were used in perfect binding "one-shot" process with hot-melt adhesive (Planatol HM 6010). Optimum adhesive binding method (text block spine treatment, adhesive bond application) was performed according to preliminary test and standard conditions (ISO 187, 1180, 3219). The paper grain direction runs parallel with text block binding edge. "Flat-back" adhesive binding is method of adhering loose leaves together at the binding edge into text block. The binding edges are filled with rigid adhesive and loose leaves are locked in fixed text block spine without radius.

Ten samples for each text block (N_80KB, V_80KB) were aged using standard technique for accelerated ageing: The high moisture-low heat ageing based on standard ISO 9142 (23 °C and 90 % relative humidity) for 1 and 2 years ageing.

The main text block quality of adhesive joints is its strength, which depends on both adhesion of adhesive to adherends and cohesion of the paper structure. The adhesive joint strength result explains text block binding quality. A binding endurance pull test determines the uniform force required to pull a loose leaf along the binding edge. The pull test measures tensile strength of loose leaf and pulling it from bond line or adhesive-adherend layer. The total load force is divided height by the loose leaf binding edge in centimeters to give its pull unit (N/cm)[12]. The result F_z (N/cm) was compared with a rating of adhesive joint strength (bad, sufficient, good and very good binding strength) according to FOGRA guidelines for page pull test [13,14]. The results are presented as the Tensile Index (Nm/g), due to comparative high paper grades strength and text block binding strength.

In the second part of research, the high grades paper properties measurements were included in order to compare paper properties towards the adhesive joint strength. Determinations of elementary, chemical, surface and mechanical paper properties was performed by ISO 187, 536, 534, 2758, 8791–2, 1924–2, 1974 and TAPPI T413. Furthermore, determination high grades papers mechanical property-linear elongation (strain rate), ε(%) results were included for understanding of the adhesive joint strength results in relation to artificial ageing process. The measurements of paper features are only included cross-machine direction because it lies parallel to the text block binding edge.

Results and Discussion

The high grades paper properties (N_80, V_80) are determined including Standards (Tab.1). Arithmetic value was calculated on the base of ten measurements for each paper. Paper strain rate property has the intention of achieving a marked effect on adhesive joint strength results according FOGRA value rating (8,26 Nm/g). As we have seen the both of them have shown the same in value of basic weight feature, but V_80 (mechanical pulp) has shown significant higher in bulk result than N_80 (chemical pulp). Paper bulk property increasing should have positive impact on adhesive joint strength through mechanical interlocking adhesion with HM adhesive. The great ratio of air space to solid content of paper contributes mechanical interlocking adhesion, bindability actually. Also its surface roughness and thickness properties have made significant greater in size than paper N_80. As opposed to bulky paper, wood-free paper N_80 has shown significant lower results in bulk and thickness features. Also its mechanical properties are significant better than bulky paper because the cellulose inter-fiber bonding increasing. The surface roughness result is significant lower than bulky paper, what is mostly relevant impact factor on mechanical interlocking adhesion intensity. Increasing of ash content property directly influence on adhesion reduction due to the particles of dust contribute lower ratio of air space to solid content of paper. Mechanical properties of wood-free paper is significant higher, it's as well to expect that paper N_80 significant contributes the adhesive

binding strength. The state of its being stable is clearly seen after ageing process over period of time, which is not observed in bulky paper.

Table 1: The high grades paper properties and the adhesive joint strength results

	N_80	**V_80**	ISO Unit	Standard
High grades paper properties				
Basic weight	77.94	77.69	g/m^2	ISO 536
Thickness	86.85	115.54	μm	ISO 534
Bulk	1.11	1.49	cm^3/g	ISO 534
Ash content	25.18	21.12	%	TAPPI T413
$CaCO_3$ content	15.94	21.27	%	TAPPI T413
Surface roughness $_{(A+B)/2}$	196.25	409.56	ml/min	ISO 8791-2
Tensile strength$_{CD}$	26.78	19.91	Nm/g	ISO 1924-2
Strain rate$_{CD}$	3.40	3.10	%	ISO 1924-2
Tearing strength$_{CD}$	2.06	1.56	mNm^2/g	ISO 1974
Tensile Stress$_{CD}$	24.63	15.31	Mpa	ISO 2758
Elastic modulus$_{CD}$	2.10	1.28	GPa	ISO 2758
Paper strain rate$_{CD}$				
before ageing	2.40	1.90	%	ISO 1924-2
after 1st year ageing	2.44	1.94	%	ISO 1924-2
after 2st year ageing	2.57	2.14	%	ISO 1924-2
Adjesive joint strength$_{CD}$				
before ageing	10.79	11.16	Nm/g	FOGRA (8,26 Nm/g)
after 1st year ageing	10.78	9.75	Nm/g	FOGRA (8,26 Nm/g)
after 2st year ageing	10.31	10.88	Nm/g	FOGRA (8,26 Nm/g)

The quantitative relation between two values of same feature has shown a rate one value contains or is contained within the other (Fig.1). As we have seen the better part of a properties being the similar in value including basic weight, thickness, bulk, $CaCO_3$ content and surface roughness, the while the ash content property has shown a significant deviation from each other. We should definitely notice that wood-free paper (N_80) features are reduced in relation to wood-contain paper (V_80).

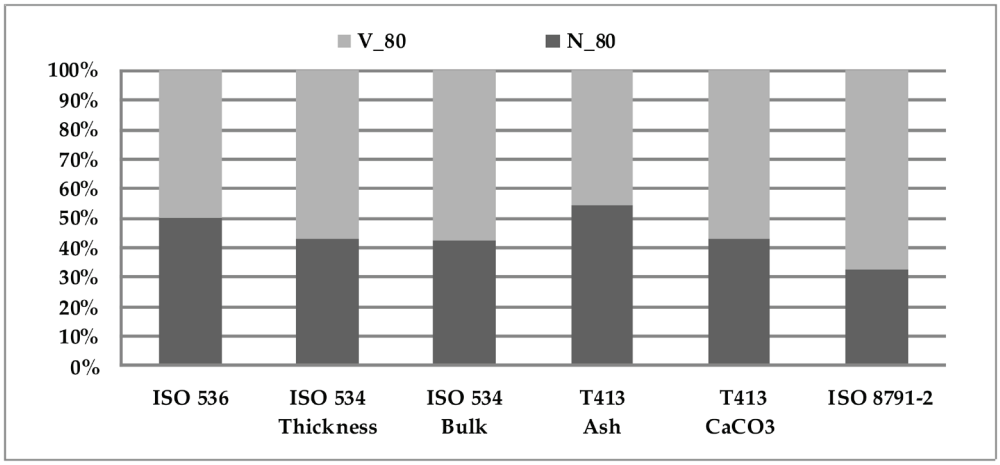

Figure 1: The ratio of the features between the high grades paper N_80 and V_80 (basic properties)

In point of fact the similar in values have not identified for mechanical features (Fig. 2). The chemical pulp (N_80) contributes significant higher the ratio in relation to mechanical pulp (V_80), the similarity between strain rate values is observed before ageing process.

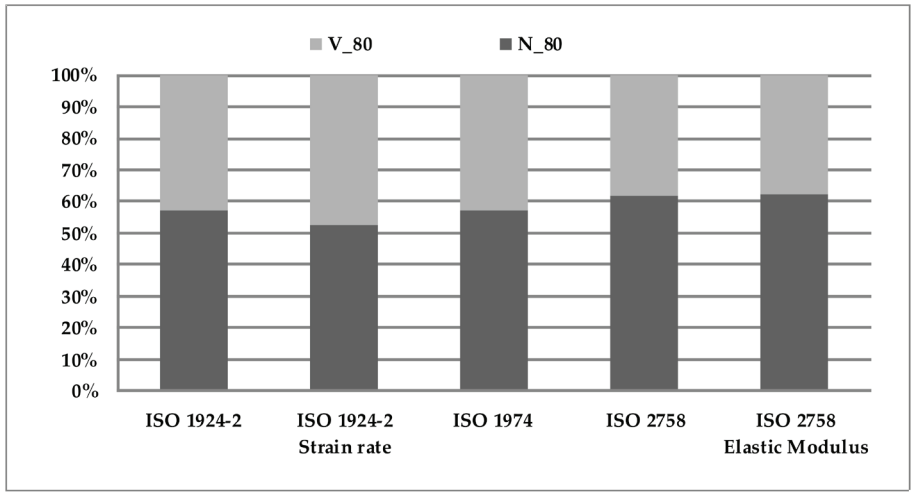

Figure 2: The ratio of the features between the high grades paper N_80 and V_80 (mechanical properties)

We have seen (Fig. 3) that the ratio of strain rate feature is remaining the same even after ageing process over period of time. These results could indicate that wood-free (N_80) and wood-contain paper (V_80) contributes the adhesive binding strength to same extent. But this is could not be right on because the fiber wall structure has different the ability to resume its normal shape after being stretched. The crystalline region of pure cellulose fiber wall (N_80) is more elastic than the amorphous region (V_80) one [9].

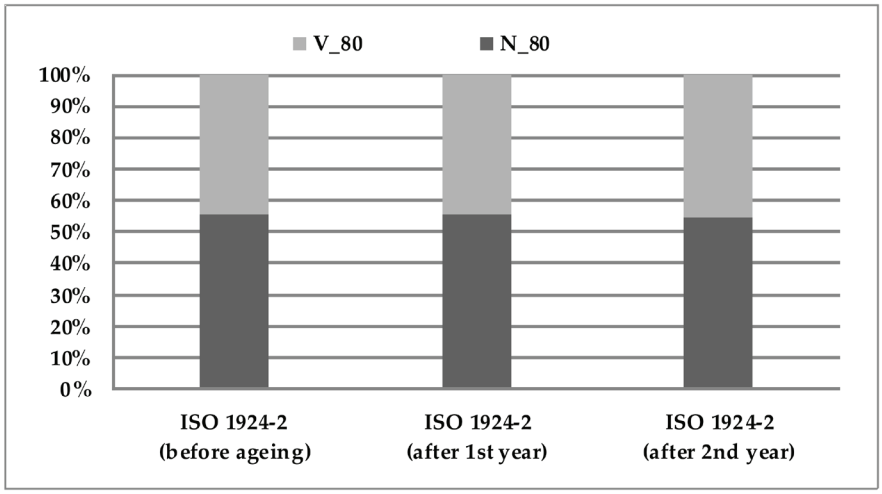

Figure 3: The ratio of the feature between the high grades paper N_80 and V_80 (mechanical property-strain rate)

The bindability of each paper (N_80; V_80) has expressed come into the adhesive joint strength result. The mechanical interlocking adhesion increasing affects how successful it is. Paper tensile strength gives adhesive joint strength in order to help achieve binding strength before and after ageing likewise. This paper feature is having a significant influence on the adhesive joint strength result to change in humid condition, as we have seen on Figure 4. The adhesive binding strength is mainly significant less than the paper tensile strength. That the appearance is normal due to paper pulled away from binding edge of text block. But the rating of adhesive binding strength for both paper is very good according to FOGRA (8,26 Nm/g). The tensile strength results (paper, adhesive joint) calculated to the Index strength value (N/mg) as a general rule the purpose of strength results comparison. As we have seen, wood-contain paper just beginning to significant change from the first to the second year after ageing in humid condition. These are the reason the presence of amorphous region in the paper and without doubt the lower value of tensile strength (AJS: 9,75 Nm/g). Its wall structure is not elastic and fiber network of paper doesn't tend to keep back the primary structure. With regard to the amorphous region becomes softer in humid condition. After the second year of ageing, the adhesive binding strength significant increasing (AJS: 10,88 Nm/g) has resulted paper higher strain rate result and its plastic deformation, brittle fracture. On the other hand, the wood-free paper (N_80) gives lower tensile strength values than bulky paper. This is explained viscoelastic behavior of the crystalline cellulose region which is stable (more elastic) in humid condition. A slight decline in the adhesive binding strength (AJS: 10,31 Nm/g) is obviously after the second year of ageing. The mechanical features are prominent in the stability of adhesive binding strength. We have noticed that are elastic modulus and tensile stress feature values providing its stability. This is particular situation doesn't live on especially under adverse conditions including wood-contain paper.

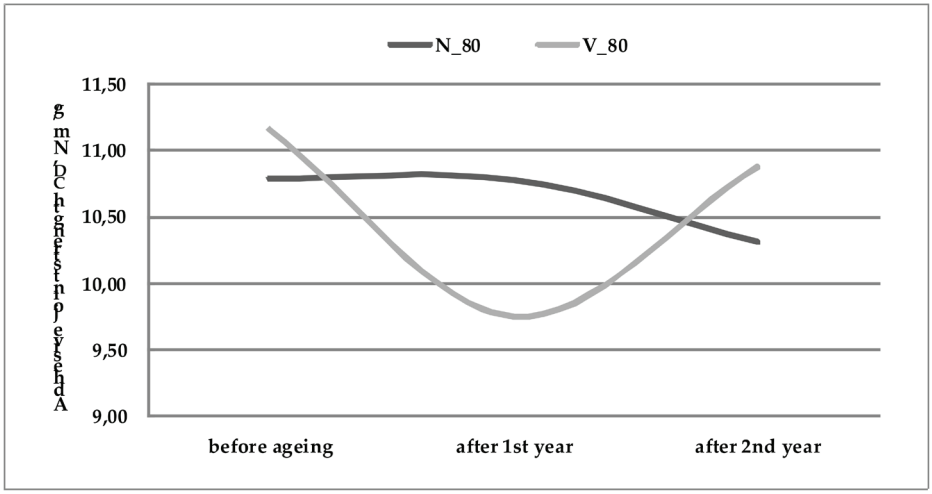

Figure 4: Adhesive joint strength results depending on ageing process in humid condition

Conclusion

On the basis of the obtained results it can be concluded that very good adhesive binding strength is successfully bring about the wood-free and wood contain paper. The results are explained from the aspect of high grades paper features. It was proved that paper basic properties are the essential factor of the effectiveness of the bindability. The mechanical properties are next important factors of the effectiveness of the adhesive binding strength after ageing process in humid condition. The hypothesis is partially proven, the paper features have caused less in result of the adhesive binding strength but the rating of binding strength is very good. For that reason that kind of high grades paper is able to be used for particular purpose of the education books, a book giving instructions and the fiction books. Also many times some of these books are affected by particular unwelcome or unpleasant condition (beach, basement, school bag)

References

1. Marra, A. A.: *Applications in wood bonding*, In: Blomquist, R. F., Christiansen, A. W., Gillespie R. H., Myers F. (Eds.) Adhesive Bonding of Wood and Other Structural Materials. Educational Modules for Materials Science and Engineering (EMMSE) Project, Pennsylvania, University Park, chap. 9., 1980, ISBN 0-8493-1588-3.
2. Tizzard, G. C., Thomas, G. C.: US Patent No. 4728688, GB, 1998.
3. River, B.H., Vick, C.B, Gillespie, R.H.: *Wood as an adherend*, In: Minford, J.D. (Ed.) Treatise on Adhesion and Adhesive, Vol.7, Marcel Dekker, New York, 1991.
4. Pizzi, A., Mittal, K. L.: *Handbook of Adhesive Technology: The Mechanical Theory of Adhesion*, Marcel Dekker, New York, 2003, ISBN: 0-8247-0986-1.
5. Johansson, P., Maritha, M: *The effect of paper parameters on the strength of adhesive bound books*, IARIGAI, 1984.
6. Pasanec Preprotić, S., Babić, D., Tuzović, A.: *The Journal TTEM-Technics Technologies Education Management*, **6**, 4 (2011)
7. Pasanec Preprotić, S., Babić D., Tuzović, A.: *Acta Graphica Journal for Printing Science and Graphic Communications*, **22**, 1–2 (2011)
8. Pasanec Preprotić, S., Babić D., Tuzović, A.: *Technical Gazette Journal* **19**, 1 (2012).

9. Niskanen, K., Kajanto, I., Pakarinen, P.: *Paper Physics, Papermaking Science and Technology* Finnish Pulp and Paper Research Institute, Helsinki, 1998, ISBN 952-5216-16-0.
10. Gregor-Svetec, D.: *Evaluation of viscelastic properties of papers*, In: Bolanča, Z. and Mikota, M. (eds.) Blaž Baromić 2006: 10th Proceedings of printing, design and graphic communications Blaž Baromić, Blaž Baromić 2006, Senj, Novi Vinodloski, Faculty of Graphic Arts-University of Zagreb. pp.187–192.
11. Roberts, M. T., Etherington, D.: *Bookbinding and the Conservation of Books: A Dictionary od Descriptive Terminology*, Library of Congress, Washington, 1982, ISBN 0-8444-0366-0.
12. Southworth, M., Southworth, D.: *Quality and productivity in the Graphic Arts, Graphic Arts* Publishing, Michigan, 1990, ISBN 0-933600-05-4
13. Fogra Forschungsbericht Nr. 71.006, Ermittlung von Qualitätsrangstufen zur Prüfung klebegebundener Brochuren mittels bauartverschiedener Prüfgeräte. München, FOGRA 2008.
14. Kipphan, H.: *Handbook of print media: Technologies and production methods*, Springer, Berlin, 2008, ISBN 3-540-67326-1.