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Deacidification and Strengthening of Degraded Papers With Aminosilanes: The Example of AMDES

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(biographies and contact information for authors can be found at the end of this paper)

Abstract

In addition to deacidification and alkaline reserve deposition, and in contrast to compounds used in current mass deacidification processes, aminoalkylalkoxysilanes (AAAS) also improve the mechanical properties of paper. This simultaneous double effect was demonstrated with aminopropylmethyldiethoxysilane (AMDES). Following treatment with AMDES, papers of various composition exhibited adequate alkaline reserve and pH, as well as a significant increase in their tensile resistance and folding endurance. These properties were partially preserved, together with a moderate molar mass retention, after hygrothermal aging of a model cotton paper. These beneficial effects of the treatment were also found for papers that had been pre-oxidized to various extents (the oxidation was intended to produce a degree of degradation more comparable to old and brittle papers). This strengthening effect of AMDES treatment was, however, found to be more modest for very highly degraded papers on which, moreover, slight yellowing was observed. This yellowing might be due to a reaction between the amine function of AMDES and the carbonyl functions on cellulose, with possible formation of imines, amines, amides, and Maillard reactions products.

Titre et Résumé

Désacidification et renforcement des papiers dégradés au moyen d'aminosilanes : exemple de l'AMDES

En plus d'assurer la désacidification et le dépôt de la réserve alcaline, et par contraste avec les composés utilisés dans les procédés courants de désacidification de masse, les aminoalkylalkoxysilanes (AAAS) permettent aussi d'améliorer les propriétés mécaniques du papier. Ce double effet simultané a été démontré dans le cas de l'aminopropylméthyldiéthoxysilane (AMDES). Une fois traités au moyen de l'AMDES, des échantillons de papiers de diverses compositions présentent une réserve alcaline et un pH adéquats ainsi qu'une augmentation importante de leur résistance à la traction et de leur résistance au pliage. Les échantillons modèles en papier de coton ont en grande partie conservé ces propriétés, en plus d'un maintien moyen de leur masse molaire, à la suite d'un traitement de vieillissement hygrothermique. Ces effets avantageux du traitement sont aussi observés pour les papiers ayant été préalablement oxydés à divers degrés (l'oxydation visait à produire une dégradation dont la nature serait plus comparable à celle de vieux papiers fragiles). Il a toutefois été établi que l'effet de renforcement du traitement à l'AMDES est moins efficace dans le cas de papiers fortement dégradés, pour lesquels un léger jaunissement a de plus été observé. Le jaunissement pourrait être causé par la réaction de la fonction amine de l'AMDES et des fonctions carbonyle de la cellulose et la formation possible d'imines, d'amines, d'amides et de produits de la réaction de Maillard.

Introduction

In libraries and archives some of the paper-based items which have acidified upon aging since their production have become brittle and often cannot be handled without risking loss of material. Deacidification is the term used for a chemical treatment in paper conservation, which involves the neutralization of the acids present in the paper and the deposition of an alkaline compound such as calcium carbonate, commonly referred to as alkaline reserve, to prevent, or at least delay, further acidification. Mass scale deacidification processes have been available commercially and used by libraries and archives in several countries for decades (Turko 1990, Carter 1996), on specific types of collections, usually at risk of rapid decay. However as none of the existing processes do strengthen the paper, they fail at offering a full solution to the problem of degraded and weakened documents. In order to provide and favour access to documents while handling of brittle items becomes restricted, the emphasis and budgets are currently geared more towards digitization of the collections.

In previous publications, a new system offering a complete response to the problem of degraded documents was investigated. The new solvent phase process based on aminoalkylalkoxysilanes (AAAS) - aminosilanes in short – was shown to simultaneously deacidify, introduce an alkaline reserve, confer fungistatic properties, improve the mechanical properties and enhance the stability of paper towards aging processes (Ipert 2005, Ipert 2006, Rakotonirainy 2008, Dupont 2010). The use as carrier of hexamethyldisiloxane (HMDS), a volatile, aprotic solvent with a low solubility parameter allows limiting the dissolution of polar substances present in the paper and fibre swelling, thereby providing a good dimensional stability during the treatment (Battelle Institut 1992). However, it was observed that for very oxidized and brittle papers the efficiency of the treatment was somewhat less satisfactory (Dupont 2010).

Aminosilanes are a large family of compounds, several of which have been tested in the past by the authors. These molecules are otherwise known in the field of nanocomposite materials and have been used to produce hybrid materials, or modify surface activity (Moon 1996, Jacob 2005, Pasqui 2007, North 2010). In this work 3-aminopropylmethyldiethoxysilane (AMDES) was introduced in papers of different composition. AMDES, a primary amine difunctional silane, has been studied in detail previously (Bennevault-Celton 2010). It was chosen here due to its capability to polymerize as a linear polymer upon hydrolysis (see Figure 1). No three dimensional structure can form that would create a cross-linked network, which brings rigidity to the system, as was shown previously by using tri-functional silanes (Ipert 2006). The modification of the physicochemical and mechanical properties upon treatment with AMDES of a recent groundwood pulp paper and one old brittle book, as well as a pure cellulose paper before and after its chemical oxidation with sodium hypochlorite, were evaluated. The oxidation was performed in order to achieve a degree of degradation which would be somewhat more representative of old and brittle papers.

Materials and methods

Materials

AMDES is a primary amine with a silicon atom bearing two hydrolysable ethoxy groups. The polycondensation of the silanol functions formed upon hydrolysis leads to linear oligomers and polymers (Figure 1).

The papers used and their characteristics are summarized in Table 1.

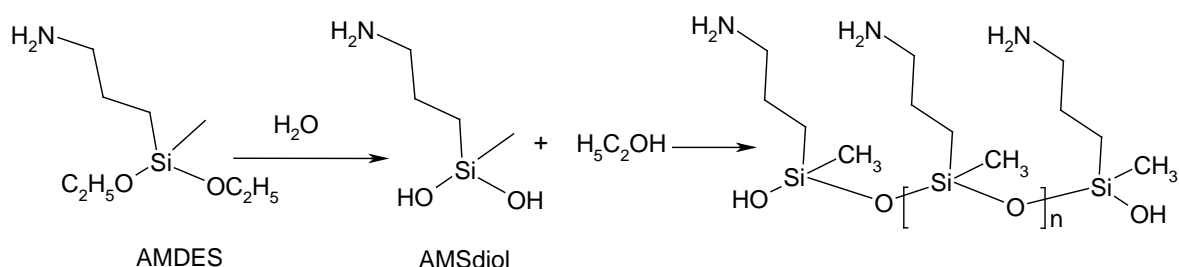


Figure 1. 3-aminopropylmethyldiethoxysilane (AMDES) and its reaction path to form 3-aminopropylmethylsilanediol (AMSdiol) (hydrolysis) and poly-AMSdiol (polycondensation).

Table 1. Characteristics of the papers used

paper	date	pulp composition	fillers	sizing	basis weight (g m ⁻²)	pH (cold extract)
P2	1990	>95% cotton	none	none	76	6.2
P3	1990	75% groundwood pulp 25% softwood cellulose	20% kaolin	alum/rosin traces casein	80	5.1
B1928	1928	50% groundwood pulp 50% chemical pulp	ND*	ND	ND	4.7
* ND: Not Determined						

Chemical and physicochemical determinations

The moisture content of the papers (MC) (% wt/wt) was determined according to TAPPI standard T 412 om-02 with a 50 mg mass of paper. The alkaline reserve of papers (AR) (meq(OH⁻)/100g) was evaluated following the standard method ASTM D4988-96R01. The cold extract pH of the papers was measured according to TAPPI T509 om-88, with a 50 mg mass of paper. The uptake in the paper (% wt/wt) was measured by weighing the samples pre-conditioned at 23 °C and 50% relative humidity (RH) before and after AMDES treatment. The

reported values are the average of the measurements on at least three samples. The copper number N(Cu) (g Cu₂O), which represents an index for compounds in paper which possess reducing properties (such as carbonyl functions), was determined according to TAPPI standard T 430 cm-99, with a reduced mass of paper (300 mg). At least three repeat measurements were done for each sample type and the average value is given.

Tensile breaking length (BL) (km) and tensile elongation at break (EB) (%) were measured according to the standard method NF: Q03-004 July 1986 using a Adamel Lhomargy instrument (DY-20B). Samples were tested at a speed of 10 mm min⁻¹, with the 100 DaN load cell. The data was processed with TestWorks 4 (MTS Systems Corp.) software.

Zero-span tensile strength (zsTS) was measured with a Pulmac instrument (TS 100) following TAPPI standard T231 cm-96. The measured value (P) was used in the modified formula $zsTS = (P - P_0) \times 5.474$ (daN mm⁻¹), where $P_0 = 2$ (instrument constant).

Folding endurance (FE) (log of number of double folds) was determined according to ISO 5626:1993 with a Tinius Olsen double fold instrument. The applied force was 0.5 kg. These mechanical properties were measured in the machine direction, on 10 strips taken from the same sample conditioned at 23 °C and 50 % RH.

Colour measurements were carried out with a hand-held spectrophotometer SP 64 (X-rite) equipped with an integrating sphere. The configuration adopted was in reflectance mode (spectral range 400-700 nm in 10 nm steps), with the specular component included, using the 5 mm diameter aperture. The colorimetric coordinates values (L,a,b)* were calculated in the CIE*Lab76 Colour System, with the D65 Standard Illuminant and 10° Standard Observer. Based on the (L,a,b)* values before and after treatment, the total colour change ΔE^* occurred upon treatment was calculated as $\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$ (Marcus 1998, p. 31). Reported values are the average of 10 measurements.

Molar mass determinations

Size-exclusion chromatography with multiangle light scattering and differential refractive index detection (SEC-MALS-DRI) was used for the determination of the average molar mass of cellulose according to a procedure previously published (Dupont 2003). A HPLC pump 515 (Waters) and autosampler ACC-3000T (Dionex) were part of the chromatographic set-up, together with a Dawn EOS MALS detector (Wyatt Technologies) and a DRI detector 2414 (Waters). The separation was carried out on a set of three polystyrene divinyl benzene columns Phenogel Linear(2) (5- μ m particle-diameter mixed bed pores columns, L×D 300 mm×4.6 mm, Phenomenex) preceded by a guard column Phenogel (5- μ m, L×D 30 mm×4.6 mm, Phenomenex). The data acquisition was carried out with ASTRA software version 5.3.1.5 (Wyatt Technologies). Each sample solution was run three times non-consecutively. The average values are reported.

Artificial aging

Papers were artificially aged at 100°C for 2, 5 and 10 days in tightly closed glass vessels following ASTM D6819-02e2.

Oxidation

Sheets of P2 were immersed in aqueous solutions of sodium hypochlorite (NaClO) at 0.26% (P2 ox1), 0.39% (P2 ox2) and 0.52% (P2 ox3) active chlorine at pH 7 (adjusted with HCl 6 N), at room temperature. The papers were thoroughly rinsed in deionized water. After gentle pressing, they were dried under vacuum at room temperature.

AMDES impregnation

The impregnation was carried out by immersing paper sheets (4 at a time, *i.e.* approximately 12 g) separated with non-woven fabric and placed on a metallic grid in 1L of treatment solution (AMDES/HMDS (% wt/wt)) at room temperature under magnetic stirring in open air. After treatment, the sheets were dried under vacuum for one hour at room temperature. Control papers were not subjected to any treatment as it was shown that their immersion in HMDS did not modify their mechanical properties.

Results and Discussion

AMDES treatment efficacy

Treatment parameters and physicochemical properties

For P2, higher AMDES solution concentrations resulted in larger uptakes after impregnation during 10 minutes (Figure 2). The impregnation time, in 10% AMDES/HMDS, from 10 to 60 minutes was also investigated with P2. After 10 minutes the uptake was of 4.9%. After 30 minutes and up to 60 minutes the uptake was 10%. Two impregnation times will be used for further experiments: 10 and 30 minutes. Figure 2 also shows that larger uptakes corresponded to increased folding endurance.

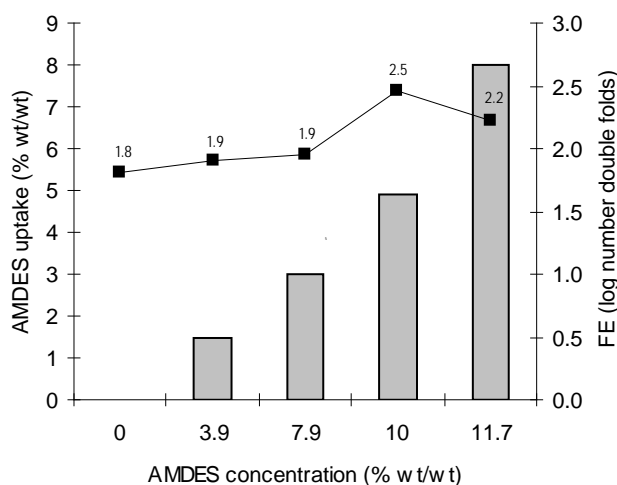


Figure 2. AMDES uptake and folding endurance (FE) of P2 Vs AMDES/HMDS concentration.

The alkaline reserve and uptake values of various papers treated with 11.7 % AMDES/HMDS are reported in Table 2, and their mechanical properties are represented in Figure 3. For the book B1928, a significant increase in BL (22%) and zsTS (21%) was observed after treatment. For P2 and P3, zsTS and BL increased slightly after the treatment. Only P2 showed a considerable increase in FE. In the case of B1928, FE remained very low after the treatment.

Table 2. Alkaline reserve (AR) and uptake of the papers treated with 11.7 % AMDES/HMDS (10 min impregnation time).

Papers	AR (meq(OH ⁻)/100g)	Uptake (% wt/wt)
P2	40	8.0
P3	26	4.5
B1928	30	6.0

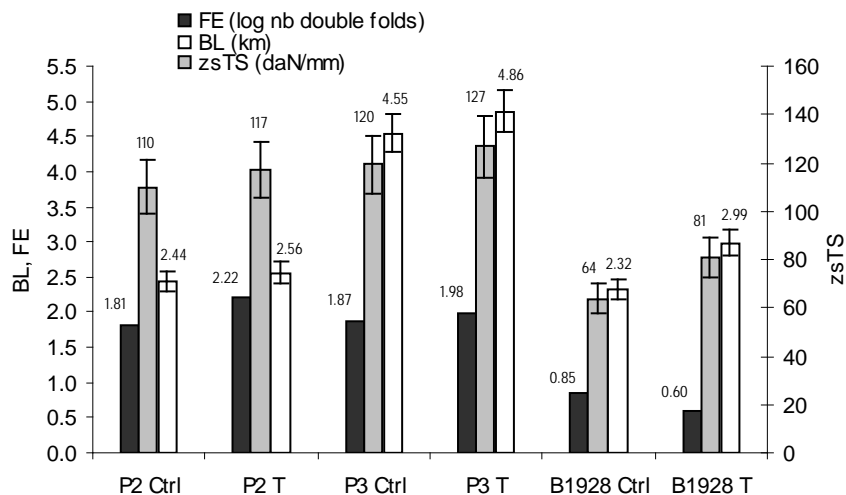


Figure 3. Folding endurance (FE), tensile breaking length (BL) and zero-span tensile strength (zsTS) of P2, P3 and B1928 with (T) and without (Ctrl) treatment in 11.7 % AMDES/HMDS.

Impact of heat/humid aging

Samples of P2 treated with 10% AMDES/HMDS (average uptake of 4.4%) were subsequently aged for 2, 5 and 10 days in order to evaluate the long-term impact and aging behavior of the treatment. Their properties were measured and compared to those of the reference papers (untreated) aged. Results are shown in Figure 4. The breaking length, which remained roughly unchanged for the reference papers aged, increased for the aged papers treated, up to five days of aging. After ten days of aging, the treated sample still showed slightly higher BL than the reference unaged (Ref A0d).

The folding endurance of the treated papers decreased slightly with aging (about 10%), roughly as much as for the untreated papers. However, the nominal values of FE for the treated papers

were all higher than for the untreated counterparts. The treatment with AMDES appears to have imparted intrinsic resistance to the paper vis-à-vis the degradation incurred during the artificial aging, up to a certain degradation state, beyond which the benefit vanishes. As expected, the alkaline reserve decreased during the aging upon production of acids by the paper, and was fully consumed after 10 days (Figure 4b). A decrease of the molar mass of cellulose was also observed (Figure 5). The weight-average degree of polymerization (DP_w) was 1792 ± 23 for the untreated sample unaged, and 1151 ± 1 after ten days (36% decrease). The DP_w of the sample treated with AMDES was 1448 ± 12 after ten days, which is 16% less decrease compared to the aged counterpart reference sample. A modest molar mass retention upon aging, due to the treatment was thus observed. For the unaged sample, DP_w was 1816 ± 3 after treatment, showing that AMDES did not modify the macromolecular properties of cellulose.

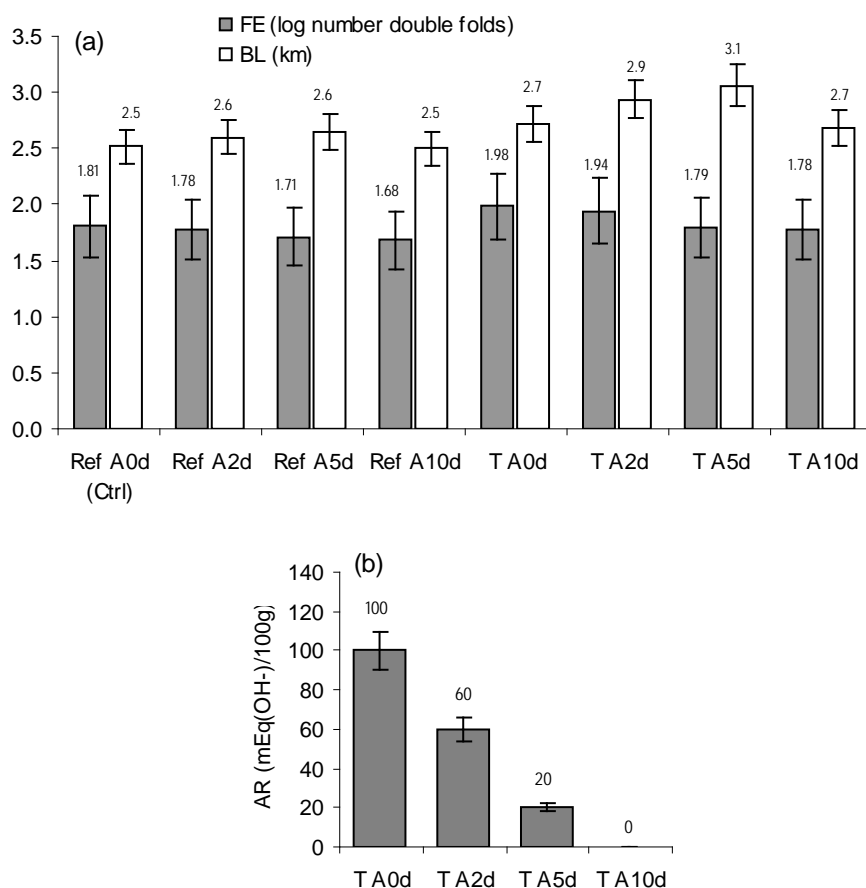


Figure 4. Folding endurance (FE) and breaking length (BL) (a) and alkaline reserve (AR) (b) of P2 reference (Ref) and P2 treated (T) with 10% AMDES/HMDS, unaged (A0d) and aged 2 (A2d), 5 (A5d) and 10 (A10d) days.

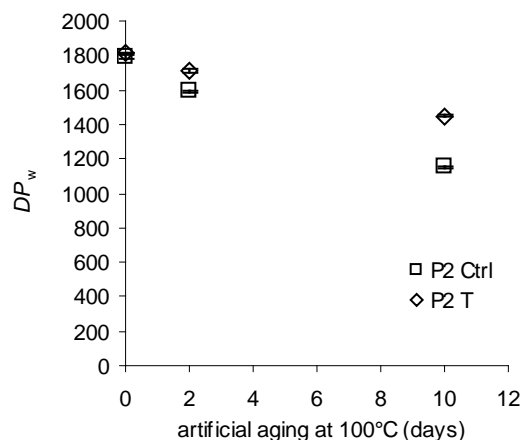


Figure 5. DP_w of P2 control (Ctrl) and P2 treated (T) with 10% AMDES/HMDS Vs aging time.

Impact of chemical degradation with NaClO

Attack of cellulose with sodium hypochlorite (NaClO) has been characterized to happen randomly in the accessible areas of the fibers, and lead to considerable chain scission, as well as to the formation of carbonyl groups (aldehyde, ketone, and carboxyl groups) on C2, C3 and C6, and short chain organic acids (Lewin 1962, Potthast 2006). The nature and the relative amount of the carbonyl functions produced depend largely on the pH; oxidation at neutral pH creates predominantly aldehyde and ketone functions.

The results of the analyses are presented in Table 3. The values obtained for N(Cu) confirmed that the oxidation at neutral pH created carbonyl functions on cellulose, the quantity of which increased with NaClO concentration. The decrease in the degree of polymerization, weight and number average DP_w and DP_n , respectively, clearly indicates that extensive cleavage of the β -(1-4) glycosidic bond occurred with oxidation. The moisture content of the papers decreased upon degradation, which was expected as degraded paper has lesser capacity to retain moisture. The oxidized papers show smaller AMDES uptake than the reference paper. This could be the result of the smaller moisture content in the paper, and/or the hindered possibility to form hydrogen bonding with AMDES due to the high proportion of carbonyl groups on cellulose, as proposed in a recent study (Souguir 2011). The pH values of the oxidized papers remained quite comparable, the acids produced during the oxidation being washed away by the water rinsing. As expected, after treatment, the pH increased considerably, confirming the efficient deacidification and alkaline reserve deposition.

One drawback was that the treatment brought some discoloration to the paper. Although the yellowing was below the commonly accepted perceptible limit in the case of P2 reference ($\Delta E^* < 1$) (Marcus 1998 p31), it was slightly larger ($1 < \Delta E^* < 3$) for all the oxidized papers. This could possibly arise from the reaction of the amine groups of AMDES with the carbonyl groups on cellulose, forming imine, amine, amide functions and Maillard reactions products (Hodge

1953, De la Orden 2006, Martinez Urreaga 2006). This observation is consistent with the decrease in N(Cu) of the treated oxidized papers as compared to their untreated counterpart samples, as under that hypothesis, the carbonyl function would be unavailable to titration. Unfortunately, attempts to determine these chemical functions using Fourier transform infrared spectroscopy were unsuccessful, probably due to their small concentration in the paper.

Table 3. AMDES uptake, cold extract pH before and after AMDES treatment (pH_{bef} , pH_{aft}), copper number before and after AMDES treatment ($\text{N}(\text{Cu})_{\text{bef}}$, $\text{N}(\text{Cu})_{\text{aft}}$), trichromatic coordinate after treatment b^*_{aft} , and total color difference ΔE^* (between a given sample and his AMDES treated counterpart) for P2 reference and P2 oxidized.

	Uptake (% wt/wt)	pH_{bef}	pH_{aft}	MC (%)	DP_n	DP_w	$\text{N}(\text{Cu})_{\text{bef}}$ (g Cu_2O)	$\text{N}(\text{Cu})_{\text{aft}}$ (g Cu_2O)	ΔE^*	b^*_{aft}
P2 Ref	11.2 ± 1.4	6.3 ± 0.3	9.7 ± 0.1	6.2	997 ± 11	1972 ± 43	0.28 ± 0.04	-	0.79 ± 0.1	-1.44
P2 ox1	7.0 ± 1.7	7.1 ± 0.1	9.7 ± 0.3	5.5	789 ± 45	1470 ± 20	1.0 ± 0.1	0.87 ± 0.13	1.08 ± 0.28	3.56
P2 ox2	6.9 ± 0.7	6.8 ± 0.2	9.7 ± 0.2	5.3	545 ± 35	1158 ± 23	4.30 ± 0.3	3.48 ± 0.35	2.05 ± 0.93	6.37
P2 ox3	6.5 ± 1.8	6.4 ± 0.3	9.7 ± 0.2	5.2	249 ± 26	681 ± 23	5.31 ± 0.06	3.45 ± 0.37	2.86 ± 0.36	7.51

Figure 6 (a) shows the relation between the degree of oxidation of cellulose and the mechanical properties. The values of zTS for the oxidized papers decreased with increasing oxidation. For the treated papers, the nominal values of zTS were all higher compared to their untreated counterpart. The decrease in FE with increasing N(Cu) confirmed that oxidation greatly affected the paper strength, while AMDES imparted somewhat better mechanical properties in terms of paper deformability. On Figure 6 (b) these properties plotted against DP_n indicate a similar trend, with the treated papers showing better mechanical resistance than their untreated counterpart. Accordingly, the elongation at break decreased dramatically for the oxidized papers (Figure 7). The cellulosic material became brittle after oxidation, and the degradation of the amorphous areas led to increased rigidity. After treatment, the elongation at break was roughly maintained for the moderately oxidized papers showing a better deformability capacity, but decreased for highly degraded paper. From these results it can be assumed that the inter-fiber and intra-fiber bonding of cellulose fibers was improved by the presence of the AMDES oligomers in the paper.

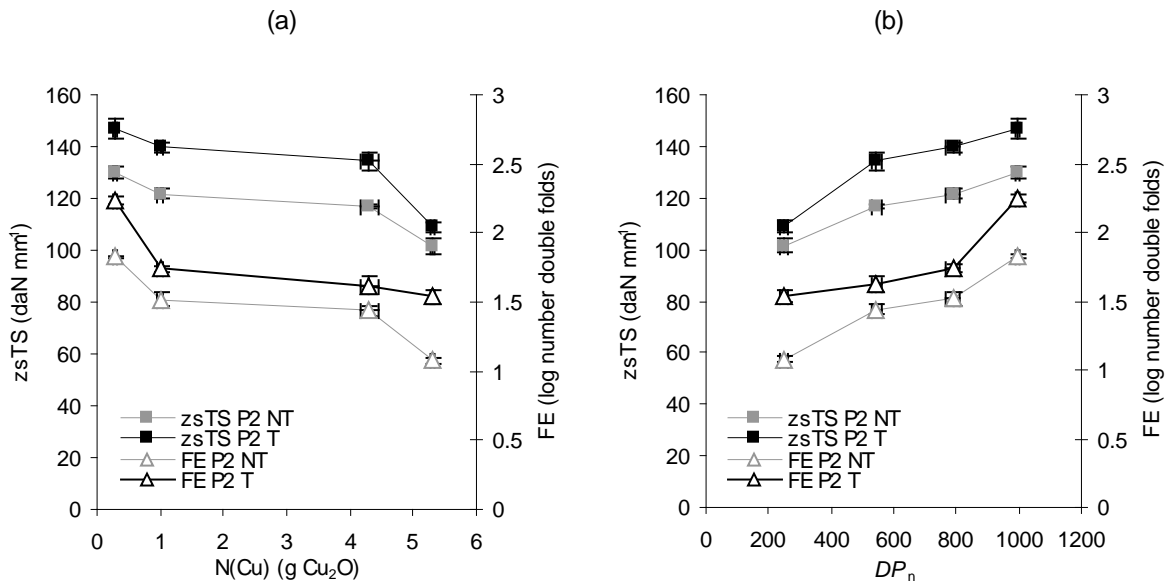


Figure 6. Zero span tensile strength (zsTS) and folding endurance (FE) of P2 untreated (NT) and P2 treated with AMDES (T) as a function of copper number $N(\text{Cu})$ (a) and as a function of DP_n (b).

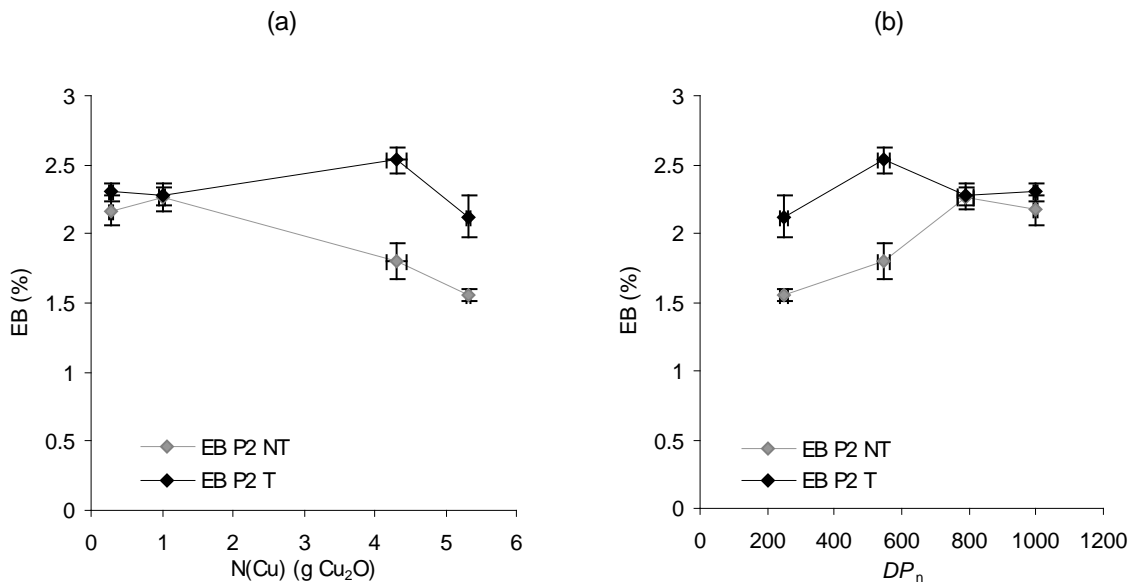


Figure 7. Elongation at break (EB) of P2 untreated (NT) and P2 treated with AMDES (T) as a function of copper number $N(\text{Cu})$ (a) and as a function of DP_n (b).

Conclusion

The investigation carried out showed that AMDES not only provided deacidification and alkaline reserve, but also improved some of the mechanical resistance properties of papers of different composition, such as breaking length, zero span tensile strength and folding endurance. This can be attributed to the formation of AMDES oligomers *in-situ*, which provides strengthening and plasticity to the paper. The mechanism of this reinforcement has been investigated in a recent publication by the authors (Souguir 2011), which showed that *in-situ* polycondensation of hydrolyzed AMDES monomers occurs in the paper to form poly-AMDES with an average DP of 10. The importance of the presence of moisture in the paper in relation with the uptake was investigated as well in the same publication. Upon treatment with AMDES, the extent of the macromolecular degradation due to heat/humid aging was somewhat diminished. The beneficial effects were also found for papers which had been oxidized to various extents before their treatment, and for which the cellulose degradation in terms of DP loss reached about 40-45%. This positive effect of the treatment with AMDES was however more modest for extremely degraded papers, which had undergone extensive chain scission (DP losses around 65-75%). However, it has to be noted that in such cases, the DP of the cellulose approached the levelling-off degree of polymerization where the length of the cellulose chains comes close to the size of the crystallite, and where virtually all the amorphous regions are lost. Such a large degradation state is rarely attained in historic paper documents. It was also observed that upon incorporation of AMDES in these highly oxidized papers, some yellowing occurred, which might be due to a reaction between the amine function of AMDES and the carbonyl functions on the cellulose, with possible formation of imines, amines, amides, and Maillard reactions products. This point remains to be investigated.

Acknowledgements

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References

- Bennevault-Celton, V.; Maciejak, O.; Desmazières, B.; Cheradame, H. "Condensation of Alkoxysilanes in Alcoholic Media: II. Oligomerization of Aminopropylmethyldiethoxysilane and Co-oligomerization with Dimethyldiethoxysilane." *Polymer International* 59 (2010), pp. 1273-1281.
- Carter, H. A. "The Chemistry of Paper Preservation: Part 1. The Aging of Paper and Conservation Techniques." *Journal of Chemical Education* 73 (1996), pp. 417-420.
- Dupont, A.-L. "Cellulose in Lithium Chloride/*N,N*-Dimethylacetamide, Optimisation of a Dissolution Method Using Paper Substrates and Stability of the Solutions." *Polymer* 44 (2003), pp. 4117-4126.
- Dupont, A.-L., Lavédrine, B., Cheradame, H. "Mass Deacidification and Reinforcement of Papers and Books VI - Study of Aminopropylmethyldiethoxysilane Treated Papers." *Polymer Degradation and Stability* 95 (2010), pp. 2300-2308.
- De la Orden, M.U., Martínez Urreaga J. "Discoloration of Celluloses Treated With Amino Compounds." *Polymer Degradation and Stability* 91 (2006), pp. 886-893.
- Hodge, J. E. "Dehydrated Foods, Chemistry of Browning Reactions in Model Systems." *Journal of Agricultural and Food Chemistry* 1 (1953), pp. 928-943.
- Ipert S., Rousset E., Cheradame H. "Mass Deacidification of Papers and Books III: Study of a Paper Strengthening and Deacidification Process with Amino Alkyl Alkoxy Silanes." *Restaurator* 26 (2005), pp. 250-264.
- Ipert, S., Dupont, A. L., Lavédrine, B., Bégin P., Rousset, E., Cheradame, H. "Mass Deacidification of Papers and Books IV. A Study of Papers Treated With Aminoalkylalkoxysilanes and Their Resistance to Ageing." *Polymer Degradation and Stability* 91 (2006), pp. 3448-3455.
- Jacob, M., Varughese, K. T., Thomas S. "Water Sorption Studies of Hybrid Biofiber-Reinforced Natural Rubber Biocomposites." *Biomacromolecules* 6 (2005), pp. 2969-2979.
- Lewin, M.; Epstein, J.A. "Functional Groups and Degradation of Cotton Oxidized by Hypochlorite." *Journal of Polymer Science* 58 (1962) 1023-1037.
- Marcus, R.T. "The Measurement of Color", pp. 31-96 in *Color for Science, Art and Technology*, Nassau Ed., Elsevier, Amsterdam, 1998.
- Martínez Urreaga, J.; De la Orden, M. U. "Chemical Interactions and Yellowing in Chitosan-Treated Cellulose." *European Polymer Journal* 42 (2006), pp.2606-2616.
- Moon, J. H., Shin, J. W., Kim, S. Y., Park, J. W. "Formation of Uniform Aminosilane Thin Layers: An Imine Formation To Measure Relative Surface Density of the Amine Group." *Langmuir* 12 (1996), pp. 4621-4624.
- North, S. H., Lock, E. H., Cooper, C. J., Franek, J. B., Taitt, C. R., Walton, S. G. "Plasma-Based Surface Modification of Polystyrene Microtiter Plates for Covalent Immobilization of Biomolecules." *ACS Applied Materials and Interfaces* 2 (2010), pp. 2884-2891.
- Pasqui, D.; Atrei, A.; Barbucci, R. "A Novel Strategy To Obtain a Hyaluronan Monolayer on Solid Substrates." *Biomacromolecules* 8 (2007), pp. 3531-3539.
- Patentschrift DE 4104515C1, Battelle Institut, 1992.
- Potthast, A., Rosenau, T., Kosma, P. "Analysis of Oxidized Functionalities in Cellulose." pp.1-48 in *Polysaccharides II* (edited by D. Klemm), Advances in Polymer Science 205, Springer-Verlag Berlin Heidelberg, 2006.
- Rakotonirainy, M. S., Dupont, A.-L., Lavédrine, B., Ipert, S., Cheradame, H. "Mass Deacidification of Papers and Books: V. Fungistatic Properties of Papers Treated with Aminoalkylalkoxysilanes." *Journal of Cultural Heritage* 9 (2008), pp. 54-59.

Souguir, Z., Dupont, A.-L., d'Espinose de Lacaillerie, J.-B., Lavédrine, B., Cheradame, H. "A Chemical and Physicochemical Investigation of an Aminoalkylalkoxysilane as Strengthening Agent for Cellulosic Materials". Submitted.

Turko, K. "Mass Deacidification Systems: Planning and Managerial Decision Making" *Association of Research Libraries*, Washington, D.C. 1990.

Materials and suppliers

Chemicals

AMDES and HMDS were purchased from ABCR, Gelest (France).

Author Biographies and Contact Information

Anne-Laurence Dupont has two Master's degrees [an MSc in Biochemistry from the University of Montpellier in France (1988) and an MSc in Art Conservation (specializing in Paper Conservation) from the University of Paris - La Sorbonne (1994)] as well as a PhD in Chemistry from the University of Amsterdam (2003). She works at the Centre de Recherche sur la Conservation des Collections (CRCC) in Paris, where she is the principal researcher in charge of the paper and cellulose section. Her current research focuses on the characterization and diagnostic methods of the degradation of cellulose and paper using microdestructive analytical techniques, the impact of the environment on cellulosic artifacts, and new methodologies for long-term stabilization of paper.

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Zied Souguir received a PhD in Chemistry and Polymer Science in 2006, with a dissertation that focused on the chemical modification of polysaccharides and the study of the chemical and physico-chemical properties of colloidal systems. In 2007, he undertook a Postdoctoral Fellowship at the Centre de Recherche sur la Conservation des Collections (CRCC), where he studied the degradation of paper at the wet-dry interface. The following year (2008), he joined the Laboratory of Physical Chemistry of Polymers and Dispersed Media (CNRS - PPMD) for a Postdoctoral Fellowship on the study of hybrid nanoassemblies and, more precisely, on the formation of hybrid inorganic-polymer nanocomposites and their stability. Since February 2010, he has been working with the CRCC and the Laboratoire Analyse et Modélisation pour la Biologie et l'Environnement (CNRS - LAMBE) on deacidification and strengthening of paper with aminosilanes.

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