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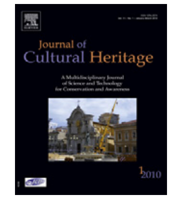

Original article

Non-invasive methods for characterisation of printed cultural heritage

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ABSTRACT

The quality of a book reprint depends on several factors, e.g. paper, typesetting, reproduction of illustrations, printing and bookbinding. The quality of the 1958 and 1988 reprints of the fairytale edition from 1944 designed by the Slovenian architect Jože Plečnik was studied using standard and other non-invasive testing methods, e.g. microscopic and spectroscopic techniques, sonic velocity, Young's modulus of elasticity, surface topography and image analysis. The chemical, physical and colorimetric properties of papers and typographic tonal density were analysed. The results showed that the reprints do not correspond to the originals. Some of the differences in the reprints, if compared with the original (e.g. typographic tonal density), could have been easily avoided, while others (e.g. structural and optical properties of paper) remain unavoidable, mainly due to the influence of internal and external factors on the ageing. The ageing process influences paper properties, since optical properties deteriorate in time. It has been concluded that a precise and systematic study of the properties of an old book should be performed before the preparation of a reprint. The results of the research have shown that the applied methods are useful and satisfactory for the characterisation of the paper properties and typography, and can be of use at the analysis of printing ink and illustration reproduction.

1. Research aims

The aim of the research was to evaluate the standard and unconventional non-invasive testing methods, e.g. microscopic and spectroscopic techniques, sonic velocity, Young's modulus of elasticity, surface topography and image analysis, in order to define the chemical, physical and colorimetric properties of papers and the typographic tonal density (TTD) of an old book, consequently leading to the production of a reprint of the best quality possible.

2. Introduction

For over 500 years, letterpress was the dominant printing technology for book printing. When phototypesetting and lithographic printing became widespread in the 1970s, the printed book turned into a low-cost mass medium. An efficient production and the availability of inexpensive paper led to the breakthrough of books as mass media. In letterpress, the printing elements (type, lines, dots) are in relief. When the printing plate is inked, the ink adheres to the raised (printing) parts and is transferred under pressure onto the printing substrate. Generally, the structure and components of the printing ink principally depend on the ink transfer mechanism and the drying of the ink on the substrate [1,2]. In letterpress printing, viscous inks, consisting of organic and inorganic pigments and binders (vehicles), are used. Sheetfed inks dry with oxidative-polymerisation [3]. In lithography, the printing and non-printing elements are on the same planographic level, but have different surface properties. In offset, the printing elements are oleophilic, whereas the non-printing elements are hydrophilic. During the printing, the non-printing elements are usually made oleophobic (ink repellent) with wetting, the ink being taken up only by the printing areas [1,2]. In offset printing, pasty inks, consisting of organic and inorganic pigments and binders, are used. Sheetfed inks dry primarily with a polymerisation reaction of the drying oil initiated by oxygen and catalysed by the drier. Offset applies a thinner ink film to the paper than letterpress, requiring that the offset inks be more pigmented than letterpress inks [3].

The book production quality is of great importance, the main parameters being the quality of the paper and printing inks, printing technique, typesetting, reproduction of illustrations and bookbinding. In order to achieve an excellent reproduction and proper print quality in a reprinted book or facsimile, it is important to have comprehensive knowledge of paper characteristics, printing ink properties and proper typesetting.

A reprint is the second or a subsequent printing of a book, with no changes other than minor corrections. A facsimile is a reprint of an out-of-print book which is an identical reproduction of the

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original [4]. This means that if a page is missing in the original, the facsimile has to lack the same page as well.

Recently, the use of non-invasive methods for the characterisation of archival or museum documents has gained recognition, especially the microscopic and spectroscopic techniques, image analysis, sonic velocity and Young's modulus [5–12]. The latter were also included in this research in order to evaluate the quality of the 1958 and 1988 reprints of the fairytale edition from 1944 designed by the Slovenian architect Jože Plečnik.

3. Experimental

3.1. Materials

The Slovenian priest and writer Fran Saleški Finžgar (1871–1963) wrote four fairytales under the common title *Makalonca*. During the Second World War, he rediscovered an old notebook with the fairytales he wrote in his study years in 1888. This research compares the original edition of fairytales, which was designed by an important Slovenian architect, Jože Plečnik (1872–1957), and was first published in 1944 in two different bindings, i.e. as a hardcover (Book 1) and as a paperback (Book 2). The book blocks of both followed an identical graphic design and typography. Apart from the complete design of the book, the architect also designed the decorations and decorative initial letters. Hand typesetting was used, and while both book blocks were printed using the letterpress technique [1], different papers were used. Since the first edition was sold out, two paperback reprints were subsequently published, i.e. in 1958 (Book 3), a year after the architect's death, and another in 1988 (Book 4), commemorating the centenary of the first writing of the fairytales. Whereas the first reprint used the letterpress technique, the second one used offset printing [1].

3.2. Methods

The differences among the original edition and reprints were researched by analysing the chemical, physical and colorimetric properties of the paper, along with the typographic properties, using standard methods as well as unconventional non-invasive testing methods, e.g. microscopic and spectroscopic techniques, sonic velocity, Young's modulus of elasticity, surface topography, SEM and image analysis.

3.2.1. Paper properties

The paper grammage was established according to the ISO 536 standard [13], while the paper thickness was measured according to the ISO 534 standard [14]. The specific volume or density is related to air permeability, rigidity, hardness and strength, and influences several physical and optical properties of the paper. The measurements were made according to the ISO 534 standard [14]. The roughness measurement of the paper was conducted with the Bendtsen method in accordance with the ISO 8791-2 standard [15]. The measurement of the paper air permeability was described according to the Bendtsen method with regard to the ISO 5636-3 standard [16]. The measurement of specular gloss was conducted in accordance with the ISO 8254-1 standard [17], using the Lehmann apparatus.

The measurement of brightness was made according the ISO 2470 standard [18]. Opacity describes the amount of light not transmitted through paper and was measured with regard to the ISO 2471 standard [19]. The colour was analysed in the CIE L*a*b* system [20] according to the ISO 5631 standard [21] with a spectrophotometer SF 600 (Datacolor, Swiss), using the C standard illumination, 2° standard observer and D/0 measurement geometry.

For a quantitative determination of the paper anisotropy, the sonic velocity method was used. The molecular orientation is characteristic of oriented polymers. Anisotropy results in different energy values of the connection between the atoms in the molecular chain. Strong covalent bonds along macromolecules and weak van der Waals intermolecular bonds result in anisotropy of several characteristics [22]. The sonic velocity was measured with an impulse detector Dynamic Modulus Tester, Pulps Propagation Meter PPM-5R (Morgan, USA). The measurements were performed on the paper surface, with the frequency of 10 kHz in machine (MD) and cross direction (CD). The time required for a signal to travel from the transmitter to a receiver was measured discontinuously, with a 1 cm step between 10 and 2 cm. The sonic velocity was calculated with Equation (1) [22,23]:

$$C = \frac{l \times 10^{-5}}{t \times 10^{-6}} = \frac{\Delta l}{\Delta t} \tag{1}$$

where

C is sonic velocity (km s^{-1}),

l is distance between piezoelectric crystals (cm), and

t is time for signal to travel from transmitter to receiver (μs).

Sonic velocity depends on the paper capability to store the kinetic energy and on the material elasticity to store the potential energy. From classical mechanics, the derivation of dependence between the module and sonic velocity in a solid state was calculated with Equation (2) [22]:

$$E = C^2 \times \rho \tag{2}$$

where

E is Young's modulus of elasticity (GPa),

C is sonic velocity (km s^{-1}), and

ρ is specimen density (kg m^{-3}).

The surface geometry is by nature three-dimensional (3D) and is termed as topography. It affects not only the mechanical and physical properties, but also the optical properties, and is one of the most important factors affecting the printability [6]. The profilometry determines the 3D surface profile without a contact and other external forces, while the contact methods, e.g. Bendtsen airflow, have some drawbacks in the paper surface research [10,11]. From the measurements of 3D surface topography, a new parameter (e.g. contact area) can be obtained which cannot be achieved with conventional analyses of two-dimensional (2D) profiles [24]. Several applications (i.e. functional properties of engineered surface) of topography reveal the main external features of the paper surface [6]. To obtain the information about the surface topography, a digital camera Olympus CX21 with the 40 × magnification and computer programs Proton and ImageJ were used. The 3D surface topography parameters, e.g. roughness parameters, were studied. The arithmetic mean roughness value (R_a) was calculated with Equation (3) and the root mean square roughness value (R_q) was calculated with Equation (4) [6]:

$$R_a = \frac{1}{L}\int_0^L \left| y(x) \right| dx \tag{3}$$

$$R_q = \sqrt{\frac{1}{L}\int_0^L y^2(x)\, dx} \tag{4}$$

where

L is line length (μm),

y is deviation between the mean line and measured point at distance x along the line,

R_a is arithmetic mean roughness value (μm), and