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FULL PAPER

ASSESSING THE RISKS OF RADIOGRAPHING CULTURALLY SIGNIFICANT TEXTILES

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X-Radiography is widely used in the investigation of works of art and other culturally significant artefacts to reveal and record details of their construction, modification and state of preservation. Radiography is considered to be a non-destructive technique but its increasing use in the study of historic textiles has prompted the testing of this assumption as X-rays and other forms of electromagnetic radiation, such as light and micro-waves, cause changes in materials which may be detrimental to their physical stability. An experiment was undertaken to test the safety of radiography for the imaging of silk fabrics as these are particularly susceptible to photodegradation. The results from a series of radiographic exposures of modern and historic fabrics show that excessive exposure to low energy X-rays produced no detectable changes in their mechanical integrity. This indicates that the customary levels of radiographic exposure used in imaging will not be detrimental to textiles.

1 Introduction

Within four months of Wilhelm Conrad Röntgen's discovery of X-rays, in November 1895, they were being used in the investigation of Egyptian mummies and, shortly thereafter, of oil paintings on wood.[1] From these early beginnings the many strands of cultural material radiography developed, including the study of human and other animal remains, metal artefacts, ceramics, paintings, documents and works of art on paper.[2] However, with a few exceptions,[3,4] textiles have not been investigated radiographically but have been regarded as obscuring layers, e.g., mummy wrappings or the coverings of upholstered furniture, through which X-rays can readily pass to produce an image of the object of real interest concealed beneath.

It is only recently, through funding from the Arts and Humanities Research Council, that the radiography of culturally significant textiles has been more systematically researched; this project was a collaboration between Mary Brooks (Textile Conservation Centre,

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Figure 1: Nineteenth century silk bodice trimmed with lace, beads and sequins. (Karen Finch Reference Collection, Textile Conservation Centre;© Sonia O'Connor, University of Bradford; reproduced by permission of the Textile Conservation Centre, University of Southampton.)

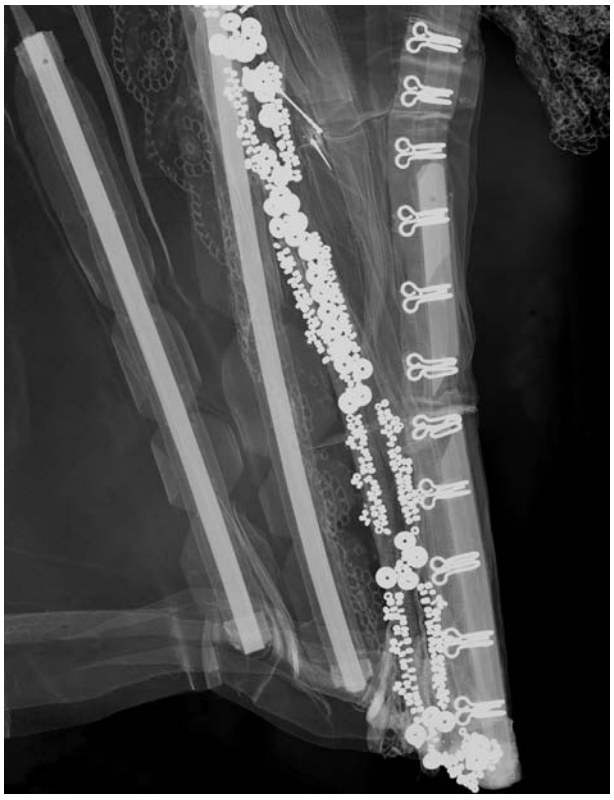

Figure 2: Low energy radiograph of the proper right front panel of the bodice. (Karen Finch Reference Collection, Textile Conservation Centre; © Sonia O'Connor, University of Bradford; reproduced by permission of the Textile Conservation Centre, University of Southampton.)

University of Southampton) and Sonia O'Connor for the AHRC Research Centre for Textile Conservation and Textile Studies based at the University of Southampton.[5,6] Low energy, high definition radiography was used in this study to reveal new evidence of the materials, construction and manufacturing techniques, use, wear, repair or patterns of decay in approximately 200 samples and textile objects from archaeological, historic, ethnographic and contemporary collections (Figures 1 and 2). As such information can be vital in provenancing or dating an object, establishing its condition and providing details of its biography,[7] this research has established radiography as an invaluable investigative tool for conservators, historians, curators and other museum professionals working with textiles.[8] Experimental work was also undertaken to establish whether or not radiography constituted a risk to these ephemeral and often highly degraded organic materials.

Organic materials are susceptible to changes induced by electromagnetic radiation, the precise processes depending on the nature of the material and the energy of the radiation. In the degradation of cultural material, the most familiar changes are those triggered by interaction of materials with light - photodegradation. Long term exposure of historic textiles to visible light typically produces colour loss in dyes and loss of tensile strength due to macromolecular chain scission in the fibres.[9] The rate of deterioration rises as the energy of the light increases and its wavelength decreases (towards the blue end of the spectrum); ultra violet (UV) radiation is particularly damaging. The very low energy X-rays used in imaging textiles, typically in the range 10 to 30 kV, share many similarities with the highest energy UV radiation as these are adjacent regions on the electromagnetic spectrum. It seems reasonable, then, to assume that the risks to textiles, either through interactions with the X-ray photons directly or indirectly, through their ionising effect, are also very similar.

The requirement for a museum to display its textile collections to the public has to be balanced against the risks involved in exposing them to light. To ensure the long-term survival of an object, overall light levels are reduced to as low a level as is practical to view the textiles whilst also retaining accurate colour rendering. Typically, the duration of exposure is minimised by restricting the period of exhibition and by the use of such devices as proximity switches. In addition, UV radiation is eliminated by careful selection of artificial light sources and the filtration or exclusion of natural light. In considering the risks that X-radiography might pose to textiles, a similar calculation has to be made by balancing information gain against potential damage before it can be recommended for the investigation of these vulnerable objects. The dose of X-rays received during imaging appears insignificant when compared to the amount of photons of light received whilst an object is displayed for an hour, a day or a week. This would suggest that radiography constitutes a very low risk to the object for potentially high gains in information. Indeed, radiography is regarded as a non-destructive investigative technique and has

been used for the recording and study of related materials, such as documents and works of art on paper, for more than 60 years with no reported evidence of X-ray induced damage.[10]

It cannot be denied that irradiating materials with X-rays causes changes. The composition of the object, the energy of the X-rays and the dose involved will all influence the nature and extent of these changes; it must also be borne in mind that not all effects will be immediate, and that exposure to radiation may affect the long-term stability of an artefact. Early worries about the possible deterioration of colours or media in radiographed paintings led some museums to ban its use on their collections. However, the work of Petertil[11], Kurt[12] and others showed that detectable photochemical changes only occurred with X-ray doses thousands of times greater than those required for imaging paintings. Undoubtedly continuous exposure would produce devastating deterioration of textiles. Mantler and Klikovits[13] carried out experimental work with X-rays on a range of papers and textiles of natural fibres to test the non-destructive nature of conventional energy dispersive X-ray fluorescence (EDXRF). Irradiation under a range of conditions produced mechanical damage, brittleness and yellowing of the samples. The yellowing of some of the specimens appeared to fade but scanning electron microscopy revealed irreversible mechanical decomposition of the fibres. Yellowing in some samples appeared after irradiation at 20 kV after as little as 10 min. Although similar beam energies and exposure times are used to produce images of textiles, the X-ray dose in the EDXRF experiments is very different to that delivered during imaging. When the respective working distances (between the object and the X-ray source) and the X-ray tube currents are taken into account, the X-ray dose received by the specimens during EDXRF are approximately 3000 times that received by a textile during imaging.[8]

2 Experimental

Although radiography does not appear to produce any immediate obvious changes in textiles, it is possible that it could change the rate and trajectory of deterioration. To assess the short and long-term effect of radiography a series of exposure and ageing experiments were carried out, followed by mechanical testing to determine the physical state of the samples. For this pilot project silk was selected because of its proven susceptibility to photodegradation.[9,14-16]

Four silk fabrics were investigated, chosen to represent a range of production treatments and physical conditions. The first was a modern unbleached, un-dyed habutae silk test fabric. The other three were a black, a pink and a puce fabric, all 18th or 19th century silks from historic collections.

Initially, samples of each of these were examined by scanning electron microscopy, using a Philips 'XL30' ESEM, employing an accelerating voltage of 20 kV and a spot size of 5 nm. Energy dispersive X-ray spectroscopy (EDS) was used to assess the elemental composition of the fibres to determine the presence of, for instance, weighting agents. The warp and weft yarns of each fabric were analysed separately; three replicate analyses were carried out for each, and average values calculated. Back-scattered electron images of each of the samples were also captured.

Each fabric was then divided and one section was exposed to a 15 kV X-ray beam generated by a Hewlett Packard 'Faxitron' model 43855 X-ray system, at approximately 1.5 mA and a working distance of approximately 0.5 m for a total of 40 min (four 10 min exposures). This gave the fabrics exposures 10 times greater than that which would have been needed to produce radiographic images on slow speed, fine grain industrial X-ray film and, perhaps, 20 to 30 times greater than that required for digital imaging systems designed for high definition industrial applications, such as computed radiography (CR).

The irradiated and non-irradiated sections were then subdivided and half were subjected to accelerated degradation. These sub-sections were placed in individual sealed tubes, with a reservoir of a saturated potassium chloride solution (to maintain a humidity of 80 ± 2% RH), which were in turn placed in an oven maintained at 85 ± 2 °C for three weeks. After ageing they were allowed to equilibrate with ambient conditions (55 ± 2% RH, 22 ± 1 °C). This yielded four sets of samples for each original silk fabric, specifically: untreated; irradiated; aged; irradiated and aged.

Finally strips 20 mm in width and approximately 70-80 mm in length, were cut from each sample and tested using an Instron '5544' mechanical tester, using a gauge length of 50 mm and an extension rate of 10 mm min^{-1}. Extension and load were measured throughout the test, to breaking point, enabling the physical properties of the materials to be determined; six replicate tests were performed for each silk sample.

To compare any X-ray induced damage that may have occurred with the effects of exposure to sunlight, habutae silk samples (comparable to those

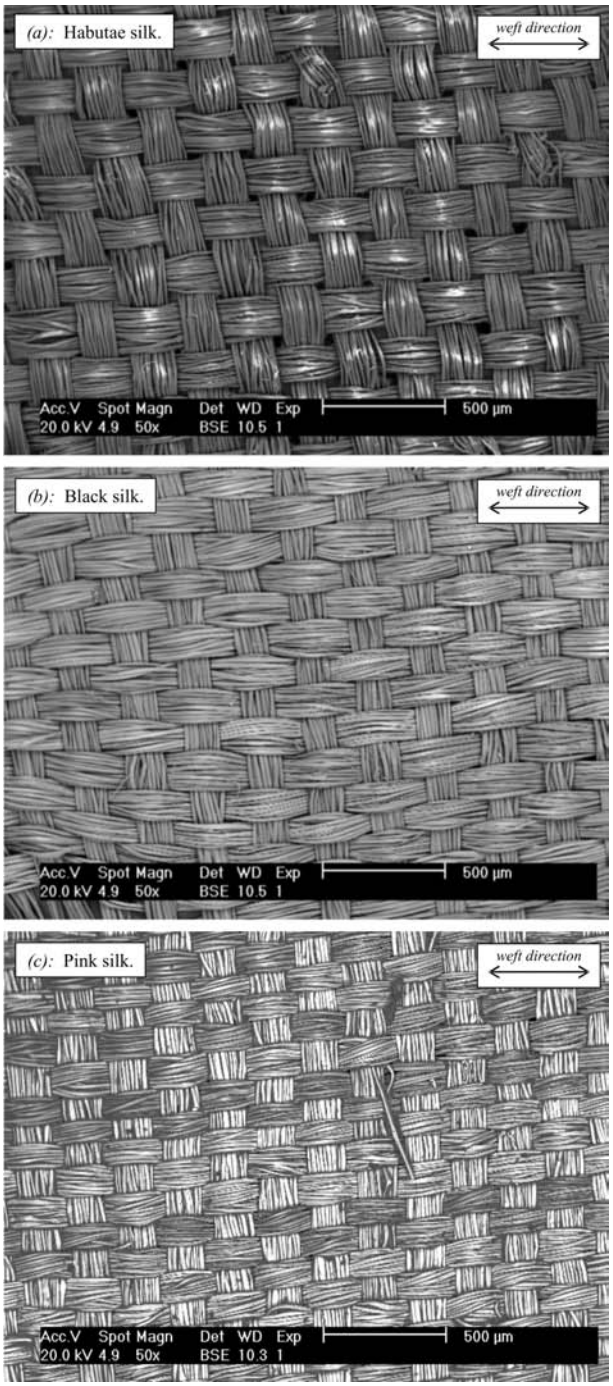

Figure 3: Back-scattered electron images of silk samples, showing representative samples of (a) an unweighted fabric, (b) a fabric in which the warp and weft yarns are uniformly weighted, and (c) a fabric in which the warp and weft yarns are weighted to different degrees.

used previously) were subjected to light ageing. This was achieved using a Xenotest 'Weatherometer', employing a xenon lamp filtered to emulate sunlight (approximately 6000 lux in a test chamber controlled at 25 °C and 60% RH).

Element	Elemental Composition / % Weight							
	Habutae Silk*		Black Silk		Pink Silk		Puce Silk	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Na	/	/	9.7	4.5	*tr*	*tr*	/	/
Mg	*tr*	*tr*	*tr*	*tr*	*tr*	*tr*	/	/
Al	*tr*	*tr*	*tr*	*tr*	*tr*	*tr*	*tr*	*tr*
Si	*tr*	*tr*	2.8	2.3	23.1	18.0	24.3	21.3
P	/	/	*tr*	*tr*	5.2	5.4	4.6	4.1
S	/	/	2.7	2.8	/	/	*tr*	*tr*
K	*tr*	*tr*	3.0	4.0	*tr*	*tr*	*tr*	*tr*
Sn	/	/	44.5	50.7	60.2	66.6	63.5	67.3
Ca	/	/	4.4	4.5	4.2	4.5	*tr*	*tr*
Fe	/	/	26.9	26.4	/	/	/	/

Table 1: Average elemental compositions (ignoring carbon, nitrogen and oxygen) for the warp and weft yarns of three historic silks. Elements present in trace quantities are indicated by 'tr'.

3 Results

The results of EDS analysis of the silks are presented in Table 1, ignoring the dominant contributions from carbon, nitrogen and oxygen (accurate to roughly 1%). The back-scattered electron micrographs are presented in Figure 3. After exposure to the X-ray beam a visual examination revealed no observable change in the colour of the silks. Figures 4 and 5 show the mean breaking load and extension at breaking values, respectively, for each of the sets of silk samples, along with error bars to denote the calculated error range of the data. It should be noted that the scales vary between the data sets.

For the habutae silk, the additional elements (excluding carbon, oxygen and nitrogen) were present in sufficiently small quantities that accurate measurement was unreliable, so are reported simply as being found in trace quantities.

4 Discussion

Elemental analysis revealed trace quantities of silicon, sulphur and calcium in the habutae silk, probably arising from the amino acid cysteine and minor mineral inclusions. In the case of the three historic silks, the additional elements were present in sufficient quantities to suggest weighting rather than simply dyes or mordants.[9,17-20] Historically, weighting agents were added to European silks, originally to fraudulently increase the weight of a fabric sold on the basis of weight, and subsequently to modify the texture and drape of the material. Initially gums, resins, waxes and sugars were used to achieve this, but by the late 18th century these materials had been largely superseded by metal salts of various types.[21] The black silk appears to have been loaded by a combination of iron and tin weighting (iron was commonly used for

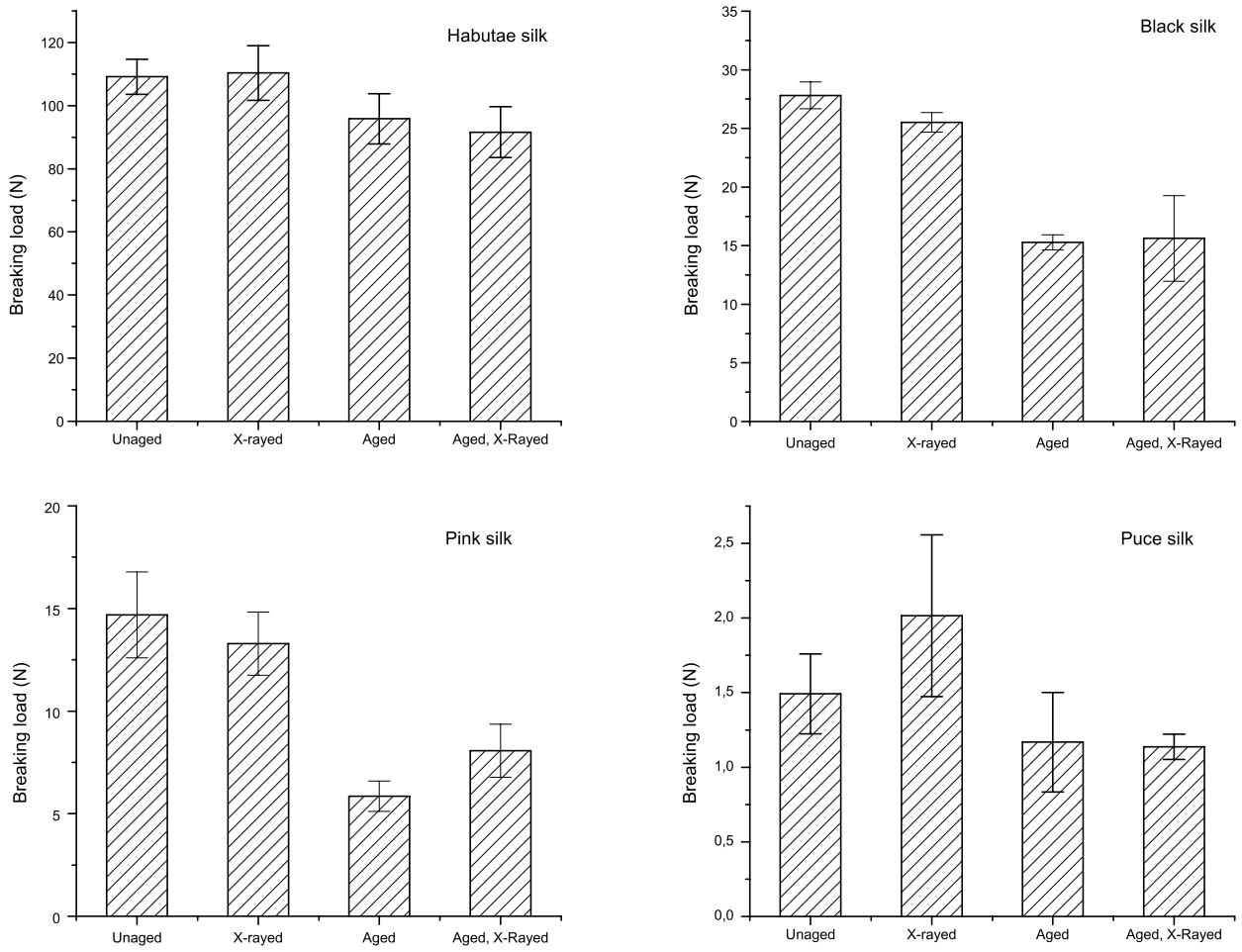

Figure 4: Average breaking loads of silk samples, with error bars based on the range of results.

silks intended for dark dying, as it functioned as both a weighting agent and a mordant), whereas the significant presence of tin and silicon in the pink and puce silks suggests 'dynamite' tin weighting.[9,17] Within measurement uncertainty, the warps and wefts of each specimen appear to have been weighted by the same method. However, the backscattered electron images (Figure 3), in which regions of greater average atomic mass show up more brightly, indicate that for the black and puce silks the degree of weighting appears to be the same for the warp and weft yarns, whereas for the pink silk, the weft yarns are more heavily weighted than the warps.

Figures 4 and 5 show that the exposure to this level of X-rays produced no deleterious effect, either immediately or after ageing, on the mechanical integrity of the fabrics. The differences observed between the pairs of irradiated and non-irradiated samples are well within the error of the experiment. Thermal ageing does produce significant deterioration of the silk fibres, as measured by both breaking strength and maximum extension, but again there is no significant difference between the irradiated and non-irradiated samples.

These results can be compared with those produced by exposure of silk to intense simulated sunlight (*Figure 6*), as noted above. Exposure to this simulated sunlight produced a marked and relatively rapid effect on the physical strength of the fibres, which falls exponentially, and which can be contrasted with the absence of measureable damage after X-ray exposure

5 Conclusions

The low energies and brief exposures involved in the radiographic imaging of textiles can be considered safe, causing at worst a negligible deleterious effect when compared with the damage caused by exposure to light during even the briefest period of study or display. Although this experiment only tested silk fabrics it is proposed in the future to extend this work to other organic textile fabrics; however, of all the natural fibres, silk is generally considered to have the greatest vulnera-

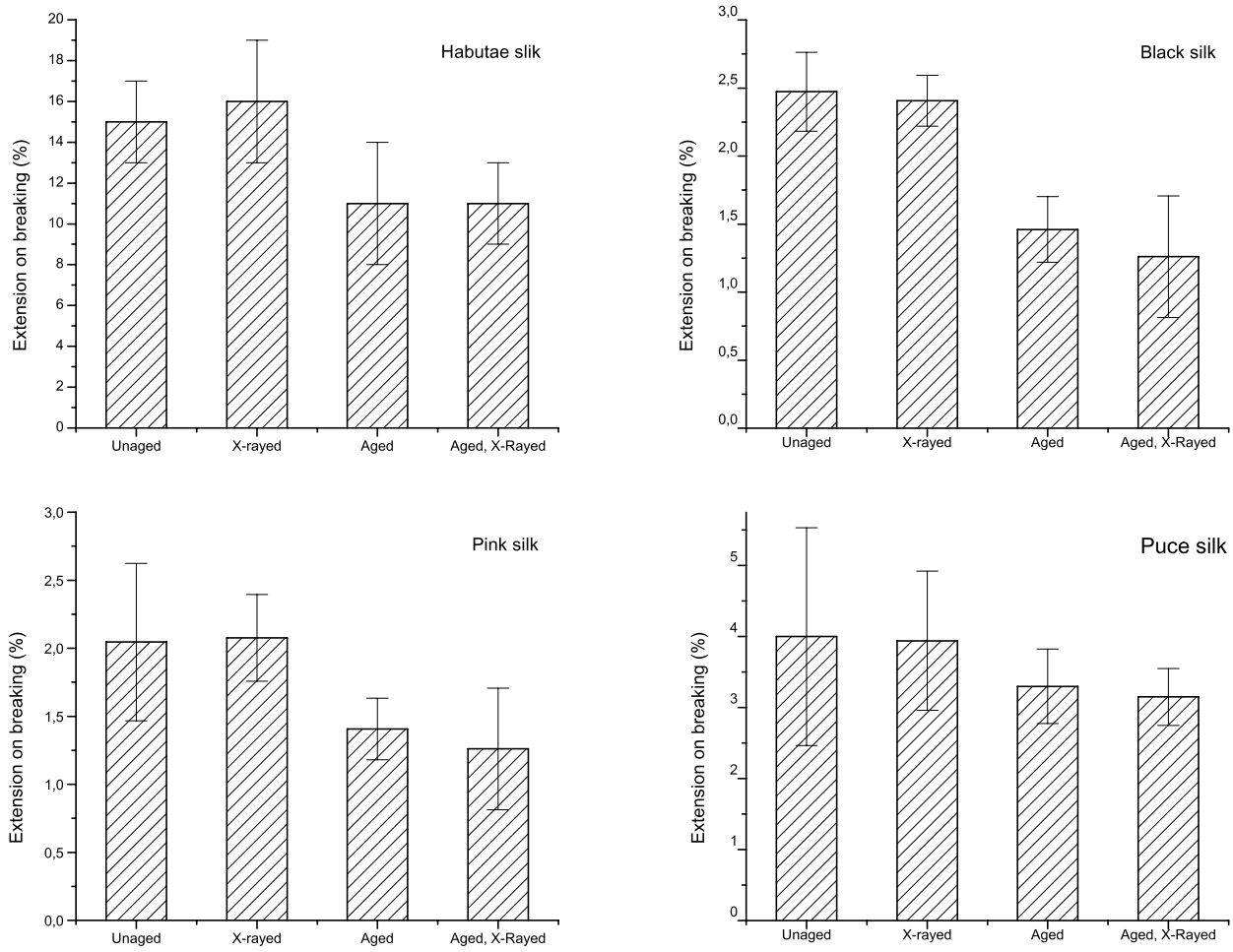

Figure 5: Average extension on breaking for silk samples, with error bars based on the range of results.

bility to photodegradative effects, which suggests that most fibres would retain stability after exposure to similar radiographic levels

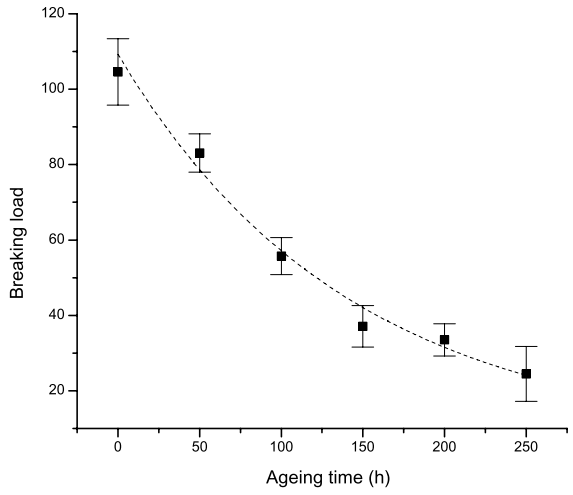

Figure 6: Average breaking loads of light aged habutae silk samples, with error bars.

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