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STUDY ON THE IR SPECTRAL STABILITY OF CAMOUFLAGE FABRICS AFTER DURABILITY TESTS

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Abstract: *The IR spectral stability of camouflage fabrics directly affects the survivability of personnel and assets in multispectral combat environments. While traditional camouflage focuses on disrupting the visual silhouette through pattern and colour, its effectiveness in the near-infrared (NIR) and short-wave infrared (SWIR) ranges is what determines its ability to bypass sophisticated night-vision devices (NVDs) and optoelectronic sensors. Military equipment designed for protection against infrared (IR) detection, such as uniforms and textile camouflage, must simultaneously meet requirements for tactical functionality, mechanical strength, and stability under various environmental conditions. Regarding the IR camouflage efficiency, the goal is to reduce the infrared signature; the materials must attenuate the wearer's thermal emission, making them difficult to detect with cameras and sensors. The purpose of this study is to evaluate the IR spectral stability after durability tests of camouflage fabrics, using spectrophotometric analysis. The reflectance index was quantitatively assessed for the five constituent colours of the camouflage pattern. For all five analysed colours, regarding the impact of abrasion, the results showed that the IR reflectance index increased compared to the initial state, due to the fact that the mechanical abrasion process induces surface gloss (sheen) on the material. Following the snagging test, which introduces structural irregularities and pulls threads, a decrease in the IR reflectance index was observed across all five colours compared to the initial samples.*

Keywords: *camouflage fabrics, infrared reflectance, durability test, military equipment*

1. INTRODUCTION

The IR spectral stability of camouflage fabrics is a critical factor in modern defence technology, determining the long-term effectiveness of multispectral concealment. While standard camouflage is designed to disrupt visual detection, its performance in the near-infrared and short-wave infrared spectrums is what prevents detection by night-vision devices and thermal sensors. This stability refers to the fabric's ability to maintain its specific reflectance properties despite exposure to environmental stressors such as UV radiation, mechanical wear, moisture, and repeated laundering [1]. The performance and durability of military equipment engineered for infrared counter-detection are defined by the following criteria: thermal signature mitigation: materials must significantly attenuate the wearer's thermal emissivity to minimize detectability by advanced IR imaging systems and sensors [2]; surface thermal homogeneity: optimized heat dissipation mechanisms are essential to minimize localized thermal gradients ("hot spots"), ensuring a uniform temperature distribution across the material surface [3]; multispectral coverage: high-performance systems maintain camouflage efficacy across critical infrared bands, specifically the MWIR (3–5 μm) and LWIR (8–12 μm) atmospheric windows, which are the primary spectra utilized in tactical reconnaissance [4].

2. MATERIALS AND METHODS

2.1 Sample and Experimental Setup

Regarding the chemical composition of the textile structures, 100% Cotton (Bbc) and 100% Polyester (PES) yarns were utilised. The ripstop structure fabric was produced on the STB 2-212 weaving machine. Manufacturing of IR camouflage printing was made using Screen Printing technology and water-based inks with Cromatex HD-10 pigments.

Fig.1. *5-color camouflage*

The developed camouflage pattern is presented in Fig. 1 and comprises 5 colours. Infrared reflectance was determined using spectrophotometric analysis to evaluate the reflectance of a planar textile substrate as a function of the incident wavelength. Reflectance, an intrinsic optical property, is defined as the percentage ratio of the total radiation intensity reflected in all directions to the intensity of the radiation incident on the material's surface. The phenomenon of reflection occurs at the interface between two optical media (Medium 1: air; Medium 2: the test material), where electromagnetic radiation is redirected into the medium of origin.

2.2. Instrumentation

All measurements were conducted according to the INCDTP internal standardised method. The spectral data were acquired using a Perkin Elmer Lambda 950 UV-VIS-NIR Spectrophotometer (Serial No. 950N6050402), which operates within a broad spectral range of 185–3300 nm.

3. RESULTS AND DISCUSSION

3.1. IR reflectance evaluation - initial fabric

The reflectance index was quantitatively assessed for the five constituent colours of the camouflage pattern: beige-brown, bordeaux, black, dark green, and green. The analysis was performed in the NIR spectrum between 800 and 1200 nm, utilising a scanning step of 10 nm (Table 1).

***Table 1**. Reflectance index values for the initial sample*

No.	Sample Description	Color	Wavelength Range (nm)	Measured Reflectance (%)
1.	Initial Camouflage Material	Beige-Brown	860-1200	81,59
		Black		77.47
		Bordeaux		94,58
		Green		97,56
		Dark green		94,98

The reflectance index values for the initial sample, printed using Grafco inks and Cromatex HD-10 pigments, demonstrate high performance within the 680–1200 nm wavelength range, with values ranging from 77.47% (black) to 97.56% (green).

3.2. Abrasion and Snagging Resistance Test (10,000 and 20,000 cycles)

Colour fastness to abrasion was evaluated using the Martindale apparatus at 1,000 and 3,000 cycles, respectively, in accordance with the SR EN ISO 12947-1 standard. Additionally, the snagging resistance was assessed using the Orbitor Pilling & Snagging Tester, following the INCDTP internal methodology. The results are summarised in Table 2.

***Table 2**. Results of the abrasion and snagging resistance tests*

<table>
<tr><th>No.</th><th>Performed Tests</th><th colspan="2">Beige</th><th>Green</th><th>Dark green</th><th>Bordeaux</th><th>Black</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Abrasion Resistance Determination</td><td colspan="2">10000 cycles No broken threads</td><td>10000 cycles No broken threads</td><td>10000 cycles No broken threads</td><td>10000 cycles No broken threads</td><td>10000 cycles No broken threads</td></tr>
<tr><td colspan="2">20000 cycles No broken threads</td><td>20000 cycles No broken threads</td><td>20000 cycles No broken threads</td><td>20000 cycles No broken threads</td><td>20000 cycles No broken threads</td></tr>
<tr><td rowspan="10">2</td><td rowspan="10">Determination of Snagging Resistance</td><td rowspan="5">U</td><td>3600</td><td colspan="4">4-5</td></tr>
<tr><td>7200</td><td colspan="4">4</td></tr>
<tr><td>10800</td><td colspan="4">4</td></tr>
<tr><td>14400</td><td colspan="4">3-4</td></tr>
<tr><td>18000</td><td colspan="4">3-4</td></tr>
<tr><td rowspan="5">B</td><td>3600</td><td colspan="4">4-5</td></tr>
<tr><td>7200</td><td colspan="4">4</td></tr>
<tr><td>10800</td><td colspan="4">4</td></tr>
<tr><td>14400</td><td colspan="4">3-4</td></tr>
<tr><td>18000</td><td colspan="4">3-4</td></tr>
</table>

The abrasion resistance of the printed textile structure is excellent, as no broken threads were identified on the material surface even after 20,000 cycles.

Following the snagging resistance testing of the printed textile substrate, grades of 3, 4, and 5 were obtained, corresponding to the different testing levels. These results indicate variable snagging behaviour, ranging from average to very good performance. A Grade 3 rating highlights a moderate occurrence of snagging defects, suggesting that the material exhibits relative sensitivity under more severe stress conditions. Grade 4 indicates good snagging resistance with minimal defects, while Grade 5 demonstrates excellent performance with no visible alterations to the textile surface. Overall, the textile substrate exhibits good snagging resistance; however, performance may be influenced by the specific testing conditions applied.

3.3. Reflectance Index Following Abrasion and Snagging Tests

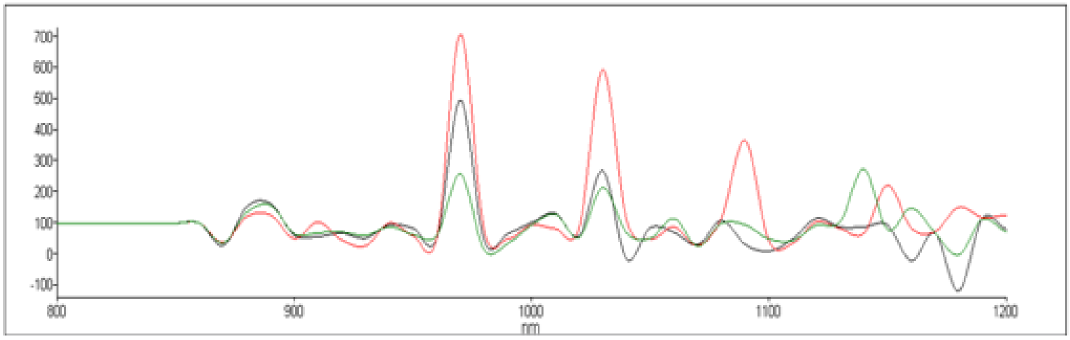
Table 3 presents the reflectance index values obtained for each colour (IR) following the mechanical stress tests: a) 10,000 abrasion cycles; b) 20,000 abrasion cycles, and snagging resistance testing.

Table 3. *Results of the abrasion and snagging resistance tests*

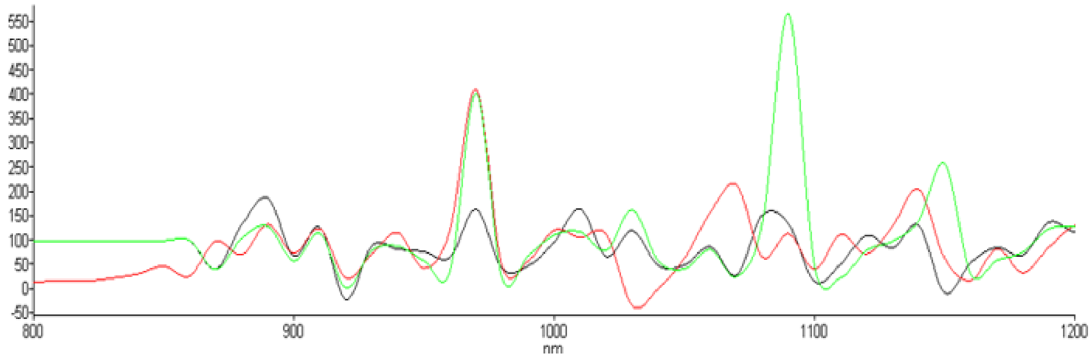
No.	Sample Description	Color	Wavelength Range (nm)	Measured Reflectance (%)		
				10000 cycles	20000 cycles	Snagging
1.	Camouflage material: abrasion and snagging	Beige-Brown	860-1200	121,5	92,93	82,22
		Black		106,47	89,35	95,9
		Bordeaux		89,62	116,17	80,96
		Green		88,65	86,53	116,48
		Dark green		105,51	142,57	92,32

Table 4 shows the overlapped reflection curves for the following colors: a) beige-brown, b) bordeaux, c) black, d) dark green, and e) green (initial state – black curve, abrasion resistance test at 10,000 cycles – red curve, and abrasion resistance test at 20,000 cycles – green curve); Table 5 shows the curves after the snagging test.

Table 4. *Overlapped reflection curves for each of five color*



a)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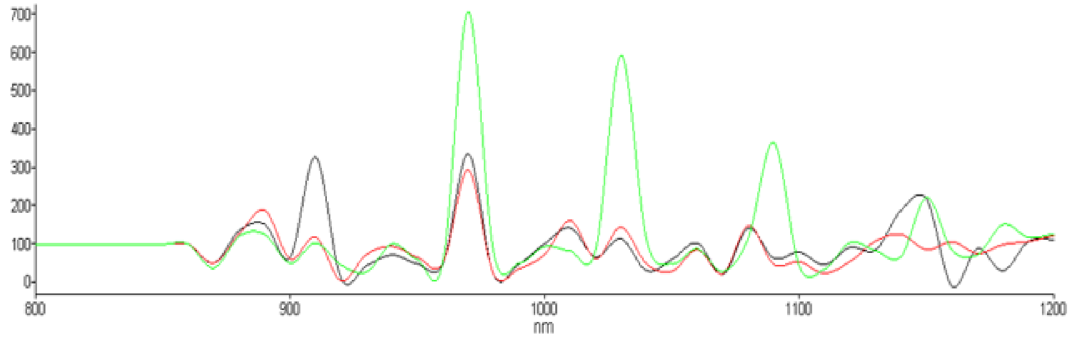
b)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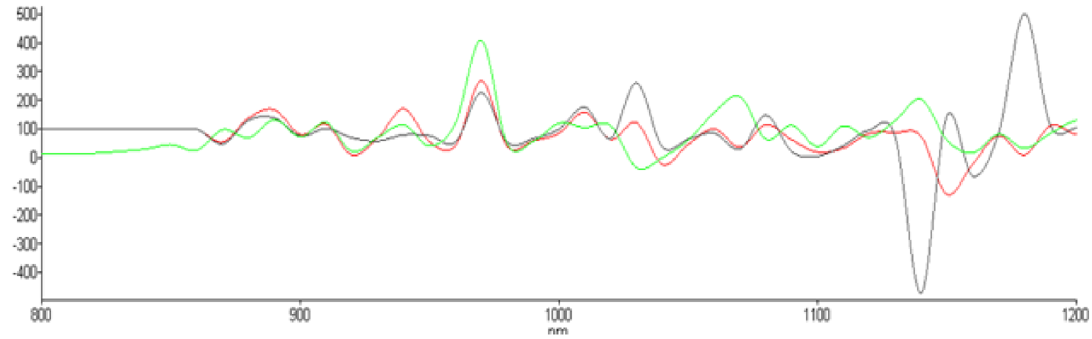
c)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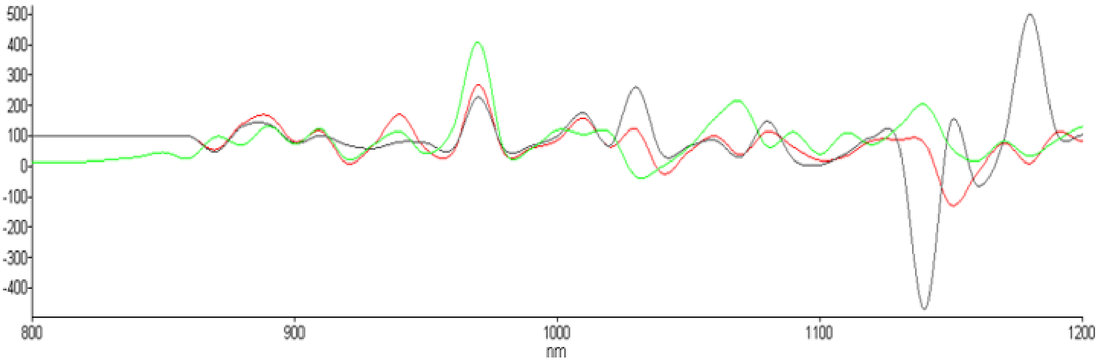
1200
nm

d)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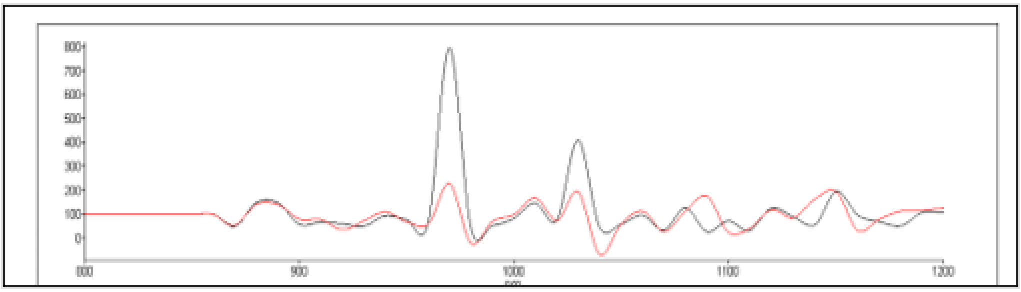
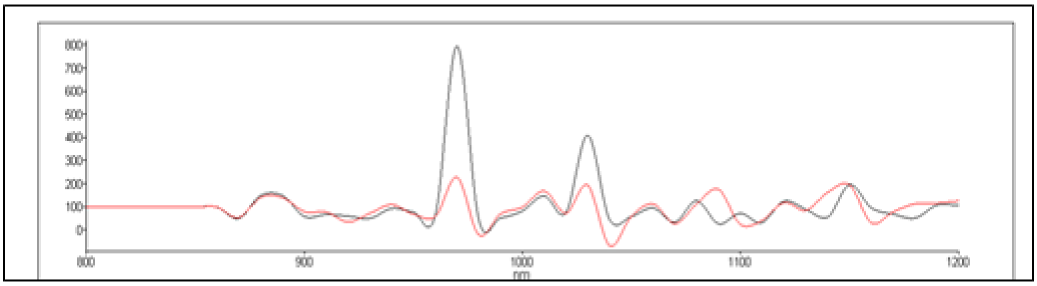
nm

e)

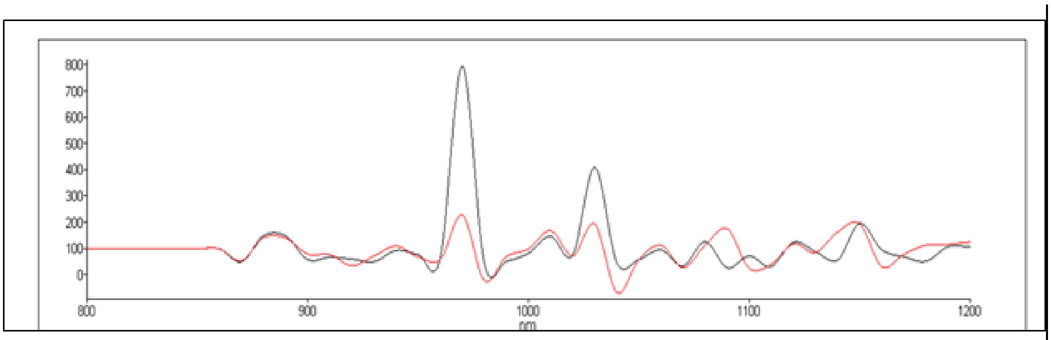
Table 5. *Overlapped reflection curves for each of five color after snagging tests*



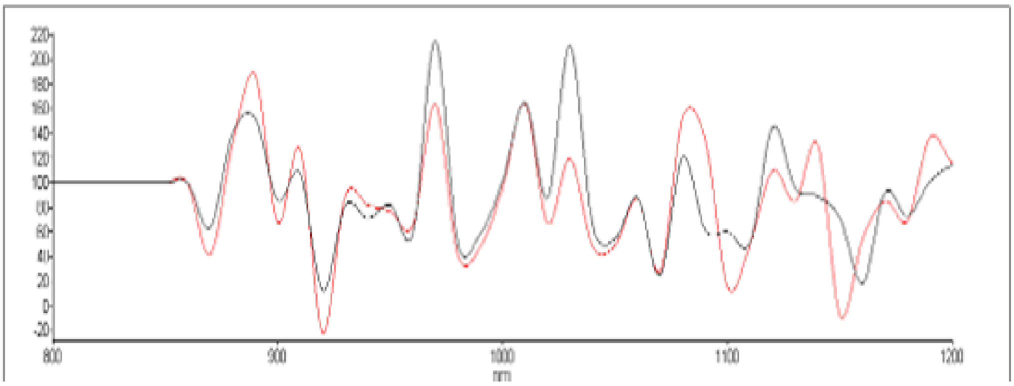
a) Beige-brown



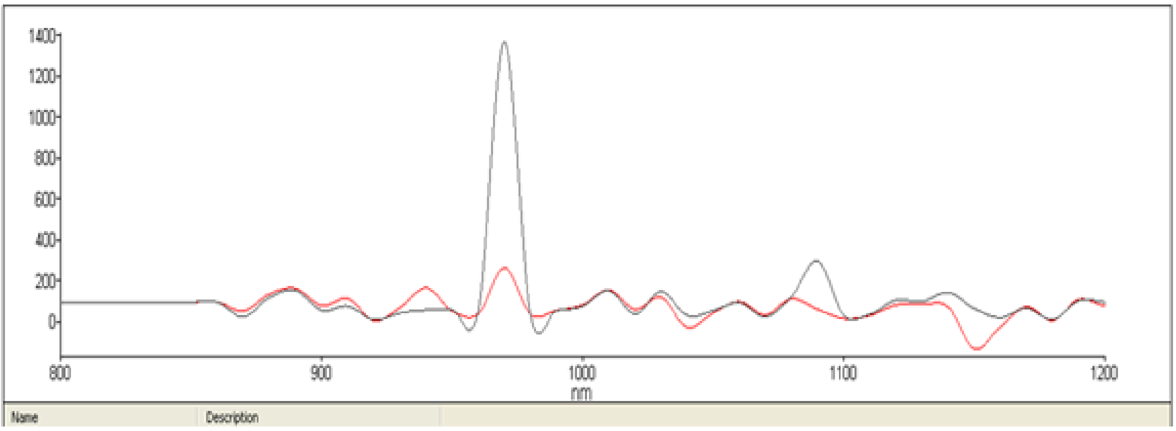
b) burgundy



c) black



d) green



e) dark green

A comparison between the initial IR reflectance values and those obtained after 10,000 and 20,000 abrasion cycles, as well as after the snagging test, reveals the following:

Impact of Abrasion: for all five analysed colours, the IR reflectance index increased compared to the initial state, due to the fact that the mechanical abrasion process induces surface gloss (sheen) on the material. Increased gloss enhances reflectance in both the infrared and visible spectra, as polished surfaces promote specular reflection over diffuse reflection. Glossy materials are characterised by a smoothed surface profile that redirects radiation (including IR) at a precise angle, where the angle of reflection equals the angle of incidence. In contrast, matte (non-glossy) surfaces diffuse radiation in multiple directions, thereby reducing the intensity of the direct reflected signal.

Impact of Snagging: Following the snagging test, a decrease in the IR reflectance index was observed across all five colours compared to the initial samples. The snagging process (which introduces structural irregularities and pulls threads) reduces specular reflection while increasing diffuse reflection (scattering) of infrared radiation. The increased surface roughness caused by snagging forces incident IR rays to reflect in multiple directions (diffuse scattering) instead of a single, coherent direction (specular reflection), effectively reducing the detectable IR signature.

3.4. Reflectance Index Following Wash Tests

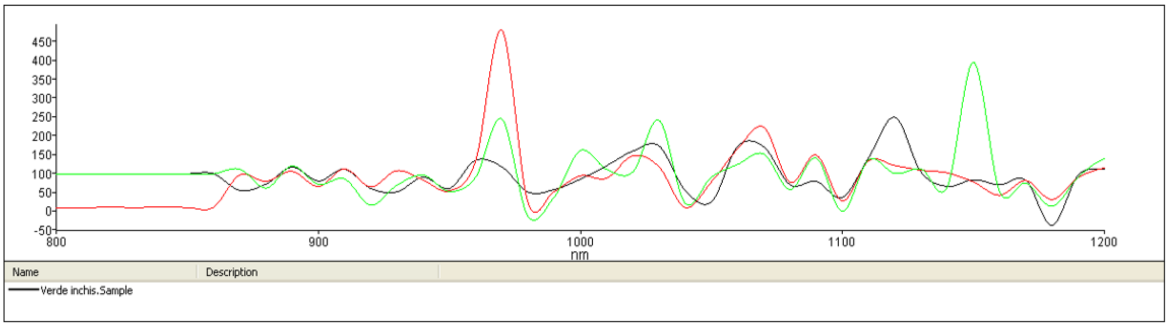
The wash fastness test was carried out in accordance with SR EN ISO 105-C06/2010 using the GIRO HW-Jams Heal washing machine, England, with the following operating parameters: temperature: 40°C; ECE phosphate-free detergent without optical brighteners: 4 g/L.Table 6 presents the reflectance index values obtained for each colour (IR) following the wash tests. Table 7 overlappes reflection curves for each of the five color afterat wash tests.

***Table 6**- Results of the wasch tests*

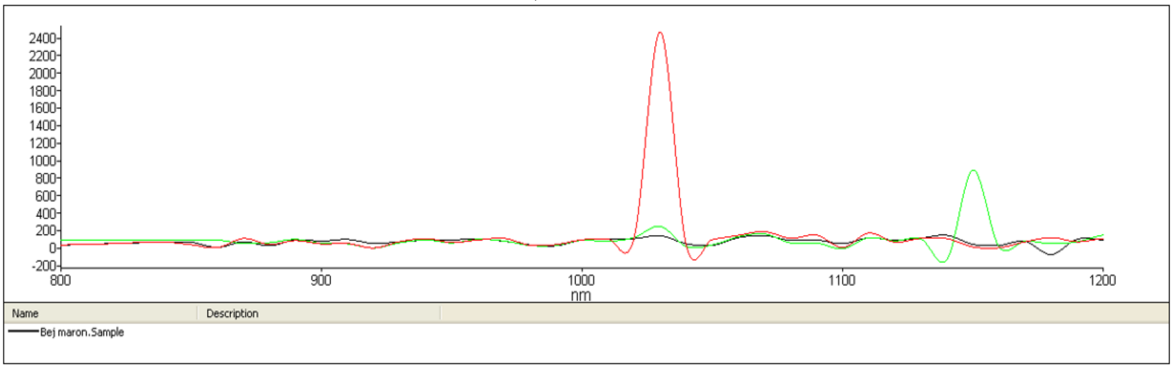
No.	Sample Description	Color	Wavelength Range (nm)	Measured Reflectance (%)	
				Wash 5cycles	Wash 10cycles
	Camouflage	Beige-Brown		101,5	141.62
		Black		101,00	95.8

1. ***T***	material: abrasion and snagging	Bordeaux	860-1200	93.82	43.72
		Green		100.64	84.67
		Dark green		88.53	101.09

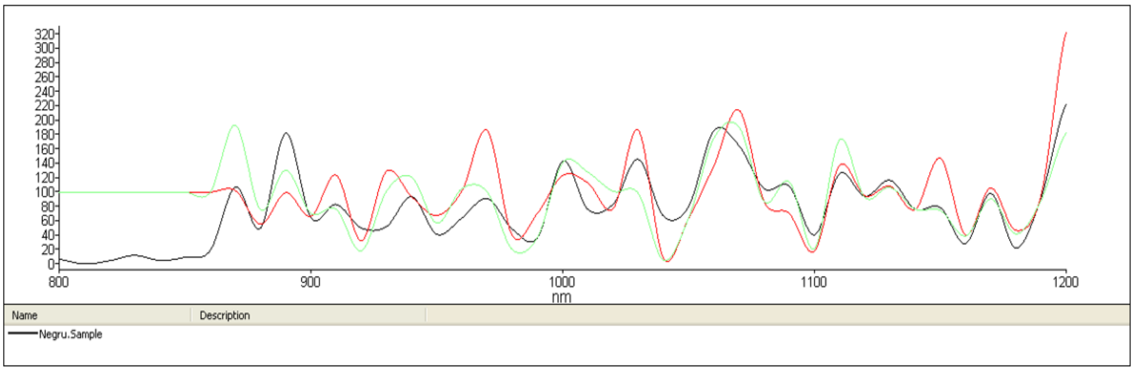
***Table** 7. Overlapped reflection curves for each of five color afterat wash tests*



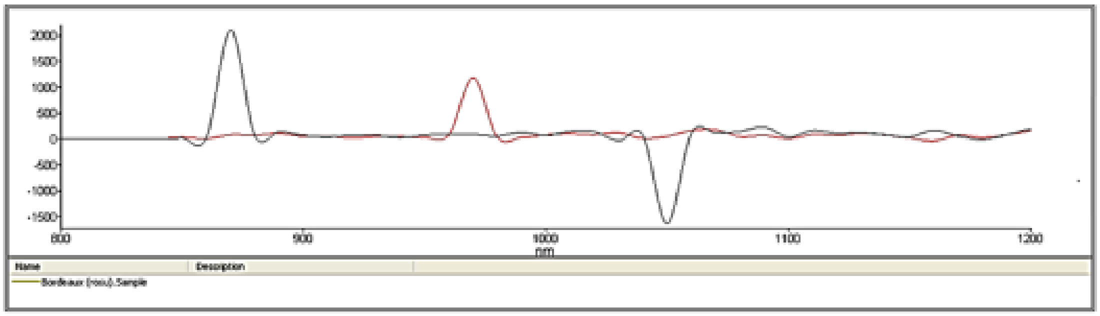
a)black



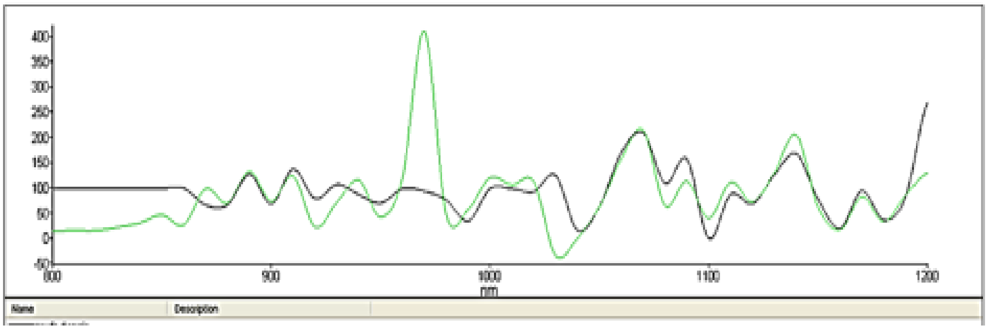
b)beige-brown



c) dark green



d)burgundy



e)green

Neutral and dark colours (black, green) showed better stability after 5 washes, while warm and intense colours (beige, burgundy) showed large variations and a tendency to fade, which may suggest the need to adjust the printing formula or pigment fixation.

4. CONCLUSIONS

The reflectance index values for the initial sample printed with Grafco inks and Cromatex HD-10 pigments in the wavelength range of 680–1200 nm are good, ranging from 77.47% (black) to 97.56% (green).
Following mechanical stress, the IR reflectance index increased after rubbing, a phenomenon associated with the appearance of superficial gloss, respectively, with an increase in specular reflection. In contrast, after hanging tests, the IR decreased due to the increase in roughness and the transition to diffuse reflection, which leads to a reduction in the infrared signature.
After 5-10 washing cycles, dark and neutral colours (black, green) showed superior chromatic stability, while warm and intense shades (beige, burgundy) showed significant variations and a tendency to fade.

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