

Research on the fabrication of camouflage coating based on Cr₂O₃ material

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ABSTRACT

This study reports on the fabrication and performance evaluation of camouflage coatings based on Cr₂O₃ nanoparticles and polyurethane resin. Cr₂O₃ nanoparticles were synthesized via a combustion method using Cr(NO₃)₃·9H₂O as the precursor and glycine as a fuel at a glycine/NO₃ ratio of 9:1. The obtained Cr₂O₃ nanoparticles, with sizes ranging from 40 to 60 nm, were uniformly dispersed within the polyurethane (PU) matrix coated onto the polyester fabric surface. Thermal imaging analysis using a FLIR BHM-Series Bi-Ocular Thermal Imaging Camera confirmed that the coatings provided enhanced and prolonged camouflage effectiveness.

Keywords: PU; Nanoparticles Cr₂O₃; Thermal photo camouflage.

1. INTRODUCTION

The rapid development of sensor technology has placed growing demands on camouflage materials in the military field [1]. If military uniforms were designed with bright colors to synchronize and easily distinguish between friend and foe on the battlefield before the nineteenth century, since the introduction of rifles capable of targeting at long distances, these uniforms have gradually become a visible weakness. To adapt to the modern combat environment, military uniforms have been updated to blend in with the surroundings, limiting the possibility of visual detection. However, after World War II, particularly during the Cold War, the emergence and rapid development of radar technology, infrared sensors, and thermal sensors set up new requirements: camouflage materials must not only match visible spectrum wavelengths but also be able to "hide" in the infrared and ultraviolet spectrums. Nowadays, with the development of multi-spectral detection systems capable of identifying targets based on thermal emission or electromagnetic reflection characteristics across multiple wavelengths, camouflage materials must be optimally designed to minimize distinct signals across the entire spectrum. Camouflage coatings are gaining popularity among researchers in camouflage materials due to their adaptability to a wide range of substrates [2-5]. An effective camouflage coating must comply with the following criteria at the same time: optical compatibility with the surrounding environment in the visible range (400 - 780 nm), a thermal emissivity coefficient comparable to the environment to avoid detection by infrared or thermal sensors, and high durability under harsh conditions.

A wide range of minerals, including Cr₂O₃, have been extensively investigated to fulfill diverse application requirements [6-9]. Cr₂O₃, characterized by its distinctive green hue resembling natural vegetation, exhibits a pronounced absorption peak at 540 - 550 nm in the visible spectrum, making it a promising material for optical camouflage. In addition, Cr₂O₃ possesses the capability to absorb and reflect infrared radiation, thereby enhancing concealment effectiveness against thermal imaging technologies [10-12]. Furthermore, Cr₂O₃ demonstrates remarkable thermal stability (melting point > 2200 °C), chemical resistance, non-hygroscopicity, and durability under various environmental conditions [13, 14]. These attributes enable Cr₂O₃ to be readily incorporated into coating layers or composite materials, thereby improving overall camouflage performance. The incorporation of Cr₂O₃ into a PU coating on PE fabric represents a novel strategy for infrared camouflage, as Cr₂O₃ provides strong mid-IR absorption while PU ensures flexibility and adhesion. This synergistic combination enables uniform dispersion, stable interfacial interactions,

and enhanced thermal signature suppression, offering a lightweight and durable textile platform for advanced IR stealth applications. Compared with other metal oxides, Cr₂O₃ exhibits superior camouflage performance, as clearly demonstrated in table 1.

Table 1. Comparison of metal oxides used in camouflage coatings and their functional characteristics.

Metal oxide	Optical properties	Infrared (IR) behavior	Advantages	Limitations	Ref.
TiO ₂	Strong UV-Vis reflectance, white color	Limited IR reflection	High chemical stability, thermal durability	No IR absorption, poor compatibility with natural surroundings	[24]
Fe ₃ O ₄	Red-brown color, good visible absorption	Weak IR absorption	Low cost, facile synthesis	Poor color fastness, limited IR effectiveness	[25]
Al ₂ O ₃	Transparent/white, low reflectance	No characteristic IR absorption	High mechanical strength, excellent thermal stability	No optical/IR camouflage effect, mainly filler role	[26]
ZnO	Strong UV absorption, white color	Limited IR shielding	UV blocking, improved photo-stability	Degradation under light and humidity, short lifetime	[27]
Cr ₂ O ₃	Natural green hue, absorption band at 540 - 550 nm	Strong IR absorption & reflection, effective thermal signature suppression	Vegetation-like color, high thermal stability (>2200 °C), chemical resistance, stable dispersion in PU	Higher cost, requires homogeneous dispersion	[28]

Various methods have been used to produce Cr₂O₃, including sol-gel [10, 15], thermal decomposition [16, 17], and hydrothermal [18-20]. Each process produces Cr₂O₃ compounds with varying properties. Based on their research of several methods, the authors' team chose the hydrothermal approach to synthesis Cr₂O₃ due to its advantages, which include creating Cr₂O₃ with high structural stability (corundum), high hardness, and, most importantly, the capacity to synthesize large quantities at a low cost. The produced Cr₂O₃ is mixed with PU to coat polyester fabric, which is then examined directly with thermal imaging equipment.

2. EXPERIMENT

2.1. Materials

Chromium (III) nitrate nonahydrate Cr(NO₃)₃·9H₂O (99.9%, Xilong, China), PA and glycine were used as the precursor and fuel, respectively, for the synthesis of Cr₂O₃ nanoparticles. Polyurethane (PU) resin served as the binding matrix for the coating formulation. Deionized (DI) water was employed as the solvent throughout the preparation process. Polyester fabric with an areal density of 125 g/cm² was selected as the substrate for coating deposition. All reagents were of analytical grade and used without further purification.

2.2. Fabrication of materials

Synthesis procedure of Cr₂O₃ (figure 1)

Dissolve 20 grams of $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ in 100 milliliters of distilled water. Add glycine at a molar ratio of 9:1 relative to $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$. The mixture was uniformly agitated at a velocity of 100 rpm and heated to 100 °C on the magnetic stirrer IKA. Upon complete evaporation of the solvent, the resultant mixture is subjected to the microwave apparatus Electrolux for a duration of 3 minutes. The resultant mixture is further heated in air for 2 hours at 500 °C using the Nobeltherm oven. The obtained product is provisionally named as M1 and remains for further processing.

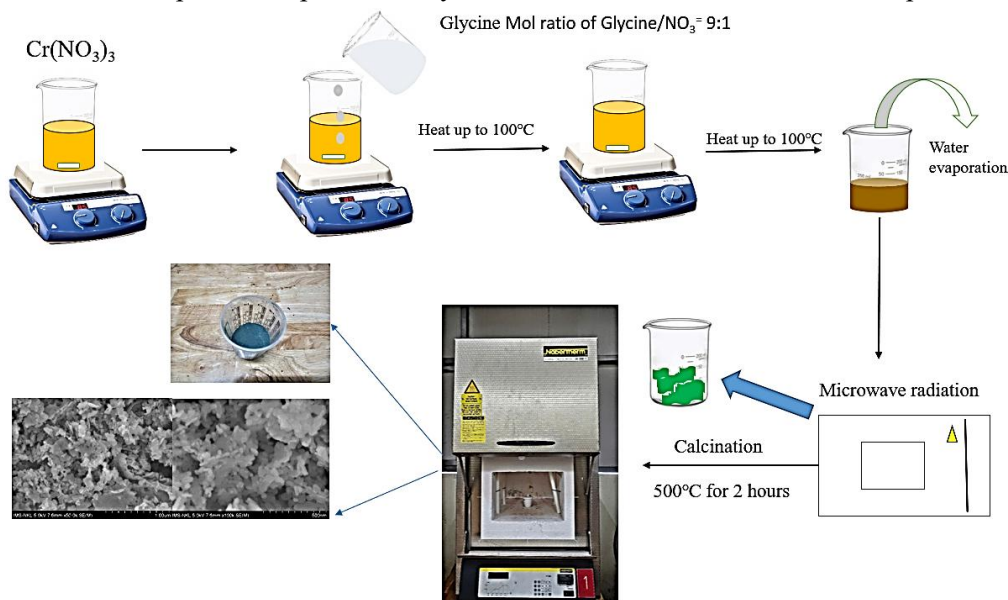


Figure 1. Schematic illustration of nano Cr_2O_3 fabrication.

The procedure for applying a camouflage coating on fabric (figure 2)

The Cr_2O_3 powder obtained from the chemical synthesis process was blended with commercial polyurethane (PU) resin at a weight ratio of 5%. The mixture was subsequently processed using a planetary ball mill at a speed of 650 rpm for 2 hours to enhance the dispersion of the nanoparticles within the polymer matrix. Thereafter, the material system was applied to polyester fabric using a three-roll mill (model YS260). The resulting sample was designated as M2 and will be subjected to further characterization in subsequent studies.

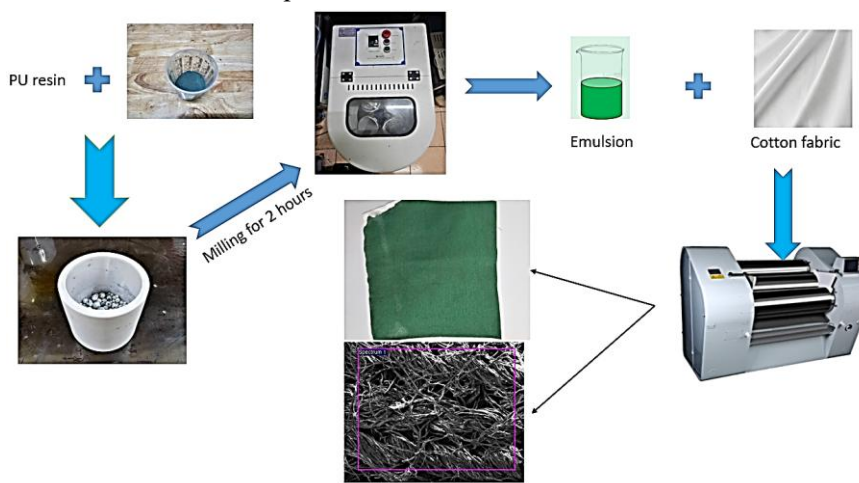


Figure 2. Schematic illustration of the fabrication process for thermal-camouflage polyester fabric incorporating nano- Cr_2O_3 additives.

2.3. Research methods

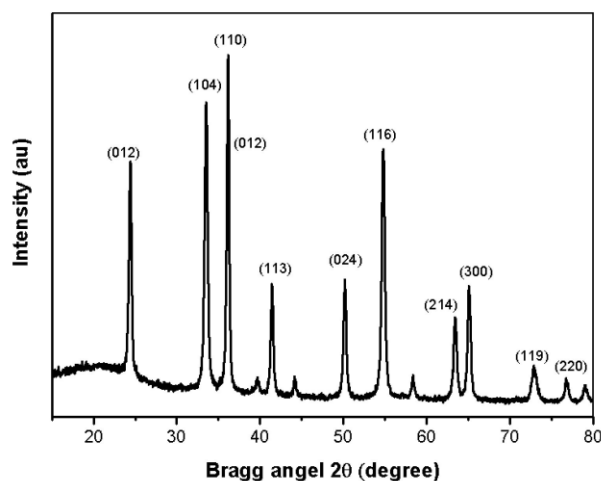
Product M1: X-ray diffraction (XRD) utilizing the Bruker D8 Advance apparatus at the Vietnam Academy of Science; scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) employing the Hitachi S-4800 apparatus at the Vietnam Academy of Science; particle size analysis conducted on the LA-960V2 apparatus at the Institute of Materials, Biology and Environment.

Product M2: Its morphology was assessed utilizing the mapping technique on the Hitachi S-4800 apparatus at the Vietnam Academy of Science; Its camouflage the effectiveness in actual environments at a temperature of 25 °C and 80% humidity was evaluated at the Institute of Materials, Biology, and Environment employing the FLIR BHM-Series Camera.

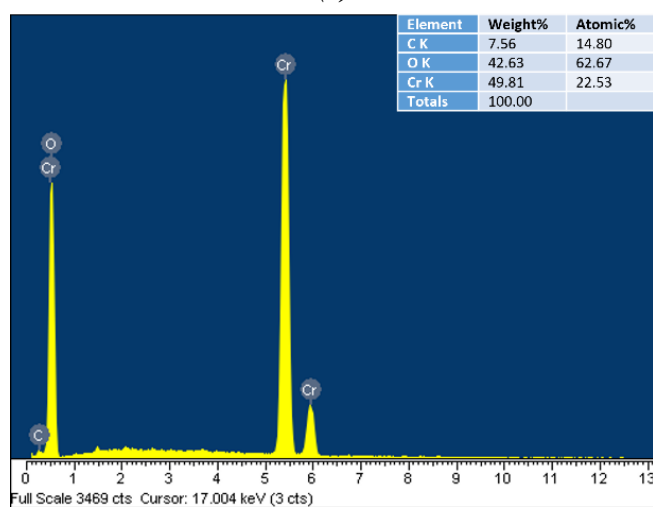
3. RESULTS AND DISCUSSION

3.1. Study on the characteristics of Cr₂O₃ material

Material M1 was obtained through calcination at 500 °C, and its crystalline structure was characterized by X-ray diffraction (XRD), as presented in figure 3a.



(a)



(b)

Figure 3. XRD (a) and EDX (b) analytical results for the Cr₂O₃ sample post-calcination.

The diffraction pattern exhibits sharp and well-defined peaks corresponding to the planes (012), (104), (110), (113), (024), (116), (214), (300), (119), and (220), which are consistent with the standard JCPDS card of corundum-type Cr_2O_3 . The pronounced intensity of the (110) reflection indicates a preferential orientation along this plane. The narrow full-width at half maximum (FWHM ≈ 0.05) of the diffraction peaks reflects a high degree of crystallinity. The average crystallite size, calculated using the Scherrer equation with a shape factor $K = 0.9$, was estimated to be approximately 40 - 60 nm [21]. These results confirm that the synthesized Cr_2O_3 possesses a well-crystallized corundum structure with uniform and relatively large crystallites [22]. The energy-dispersive X-ray (EDX) spectrum (figure 3b) confirms that the synthesized sample consists exclusively of chromium (Cr) and oxygen (O) elements. The absence of additional peaks associated with foreign elements indicates that the product is free of detectable impurities. This result, combined with the XRD analysis, confirms that sample M1 corresponds to a chromium oxide phase with a corundum-type crystal structure (Cr_2O_3).

SEM observations at different magnifications (figures 4a and 4b) reveal that the Cr_2O_3 nanoparticles exhibit relatively small sizes, predominantly distributed in the range of 40 - 60 nm. To achieve effective camouflage performance, the nanoparticles were homogeneously dispersed within the polyurethane (PU) matrix through a high-energy ball milling process.

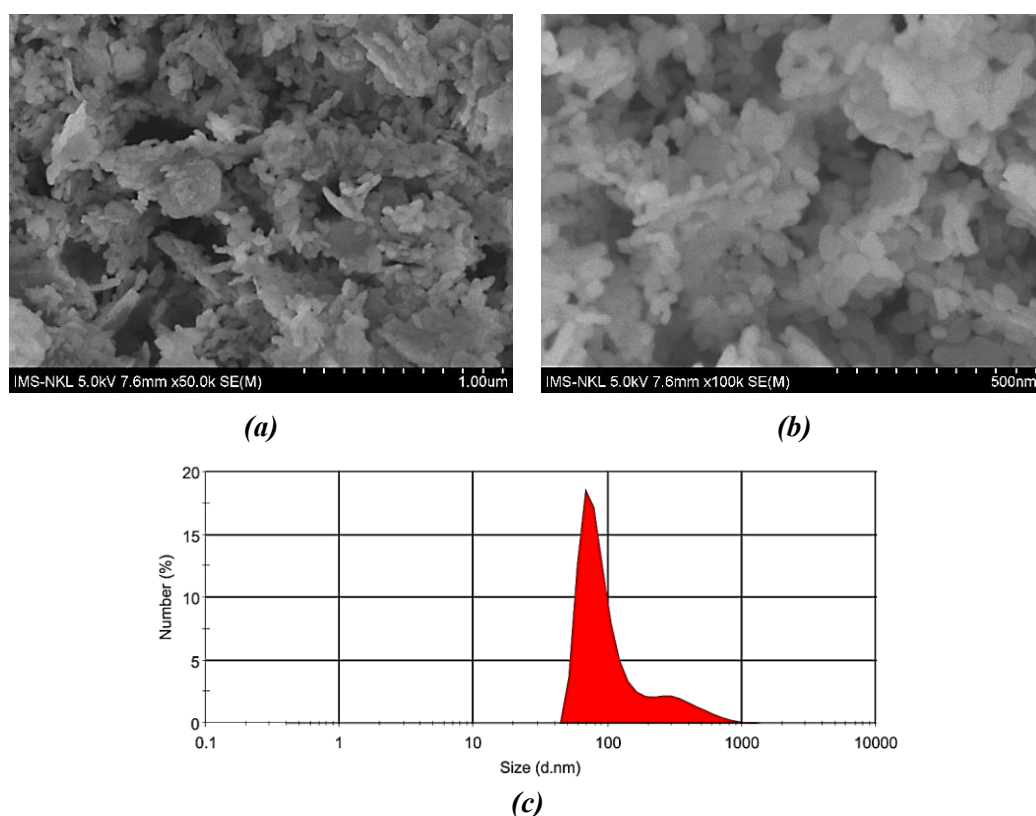


Figure 4. Results of morphological examination (a-b) and particle size distribution (c).

3.2. Study on the camouflage effectiveness of materials with coatings based on Cr_2O_3

The SEM image (figure 5a) illustrates the morphology of the polyester fabric used as the substrate for camouflage coatings. The fibers are interwoven with relatively small diameters, forming numerous voids that contribute to reduced heat transfer. In addition, the intrinsic hydrophobicity of polyester enhances its insulating capability by preventing moisture absorption, thereby improving the material's performance for camouflage applications.

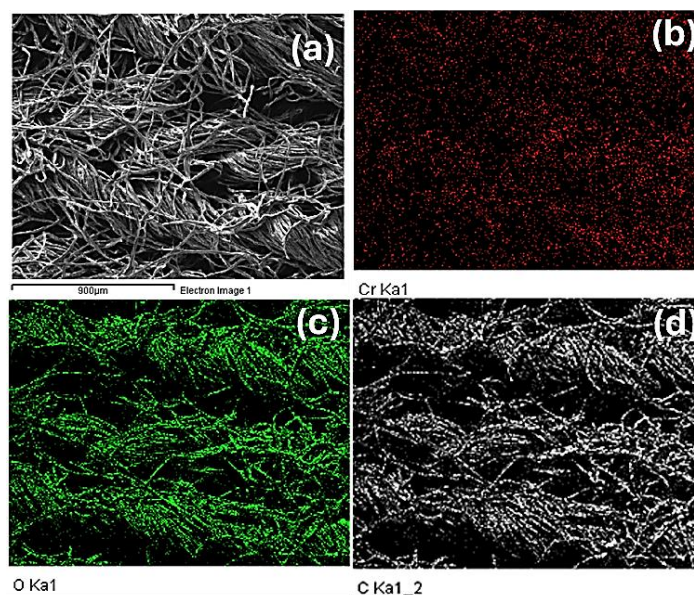


Figure 5. Mapping spectrum for the element Chromium (red dot) (b) on the fabric background (a).

The elemental mapping analysis (figures 5b, 5c, 5d) demonstrates that chromium is evenly distributed across the polyester surface. The red signals correspond to the characteristic Cr Ka1 peak, confirming the successful dispersion of Cr_2O_3 nanoparticles onto the fabric without noticeable aggregation or localized clustering. This uniform distribution is essential to ensure consistent coating performance and effective camouflage properties.

The FTIR spectrum of the PE fabric coated with PU and Cr_2O_3 exhibits characteristic bands of PE (2916, 2848, 1425 cm^{-1}), PU (broad N–H/O–H stretching at $\sim 3300 \text{ cm}^{-1}$, urethane C=O at 1642 cm^{-1} , and C–N/C–O bands at 1230 - 1030 cm^{-1}), together with a distinct Cr–O vibration at $\sim 555 \text{ cm}^{-1}$. The downshift of the C=O band and the broadening of the N–H/O–H peak suggest the formation of hydrogen bonding and weak coordination interactions between PU and Cr_2O_3 , indicating that chromium oxide is incorporated within the polymer network rather than remaining as a separate phase. This interpretation is consistent with the EDX mapping analysis, where the Cr $\text{K}_{\alpha 1}$ signal is homogeneously distributed across the polyester surface without noticeable aggregation.

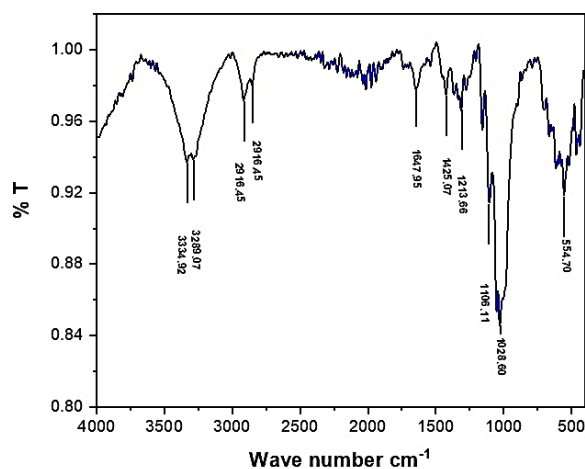


Figure 6. FTIR spectra of M2.

The FLIR BHM-Series Bi-Ocular Camera, a high-resolution portable thermal imaging device, enables the detection of objects in both illuminated and dark environments by capturing infrared (thermal) radiation. Experimental results demonstrate that fabrics coated with Cr_2O_3 -based paint exhibit thermal signatures that are nearly indistinguishable from the ambient background. As illustrated in figure 6, the coated fabric shows significantly reduced thermal contrast compared to the human body. Furthermore, the heat emitted from the Cr_2O_3 -coated surface closely matches the surrounding environmental temperature, thereby confirming the effective thermal camouflage capability of the coating.

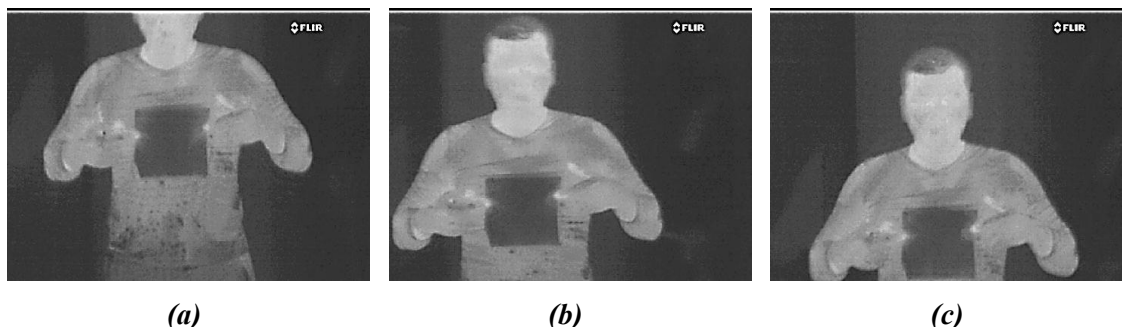


Figure 7. Camouflage fabric sample (square) positioned in front of an individual's body at various testing intervals: 5 minutes (a); 15 minutes (b); 30 minutes (c).

There is essentially no significant variation in camouflage effectiveness within the surrounding environment over extended durations, despite testing intervals on individuals ranging from five to thirty minutes.

4. CONCLUSIONS

In conclusion, Cr_2O_3 nanoparticles with a corundum crystal structure and particle sizes ranging from approximately 40 to 60 nm were successfully synthesized. A camouflage coating formulated with PU resin and Cr_2O_3 nanoparticle additives exhibited a uniform distribution of Cr_2O_3 on the fabric surface, thereby significantly enhancing its long-term effectiveness in concealing against thermal imaging cameras. These results confirm the potential of hydrothermally synthesized Cr_2O_3 for advanced camouflage applications. Future research will focus on exploring alternative synthesis routes and employing comprehensive characterization techniques to further optimize the structural and optical properties of Cr_2O_3 with the overarching goal of improving its camouflage performance under diverse environmental conditions.

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TÓM TẮT

Nghiên cứu chế tạo lớp phủ ngụy trang trên cơ sở vật liệu Cr_2O_3

Nghiên cứu này trình bày quá trình chế tạo lớp phủ ngụy trang và đánh giá hiệu quả của lớp phủ ngụy trang. Lớp phủ được chế tạo trên cơ sở của hạt nano Cr_2O_3 và nhựa PU. Hạt nano Cr_2O_3 được tổng hợp bằng phương pháp đốt cháy với tiền chất là $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ và glycine theo tỷ lệ glycine/ NO_3 là 9:1. Các hạt nano Cr_2O_3 tổng hợp được phân bố trong dải kích thước trong khoảng 40 - 60 nm và được phân tán đều trong lớp phủ trên bề mặt vải polyeste. Lớp phủ cho khả năng ngụy trang tốt trong thời gian dài trước camera ảnh nhiệt thế hệ thứ 3 không làm lạnh FLIR BHM-Series Bi-Ocular.

Từ khóa: Nhựa PU; Hạt nano Cr_2O_3 ; Ngụy trang ảnh nhiệt.