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Design of a color changing shape memory actuator

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ABSTRACT

Shape Memory Alloy (SMA) uses heat energy for actuation, there is a need for it to indicate its temperature through color change in order to avoid overheating. Therefore, in this work, a smart wire that changes color when actuated is designed and developed using thermochromics which are active mixture containing leuco dyes that is solid at low temperature but which melts at high temperature, causing the dye to change from one color to another when subjected to high temperature. Since thermochromic materials cannot be directly applied to an SMA's surface because the dyes have a slurry form and are water soluble, the thermochromic material is microencapsulated into a polymer and then applied to the SMA wire. In this work, an elastomer was impregnated with thermochromic materials in dye form to produce a color-changing polymer with which the SMA wire is coated with. The results show that the developed color changing Shape Memory Actuator not only exhibits the properties of a SMA wire but also able to give a visual indication of high temperature through its color changing properties.

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Figures and tables

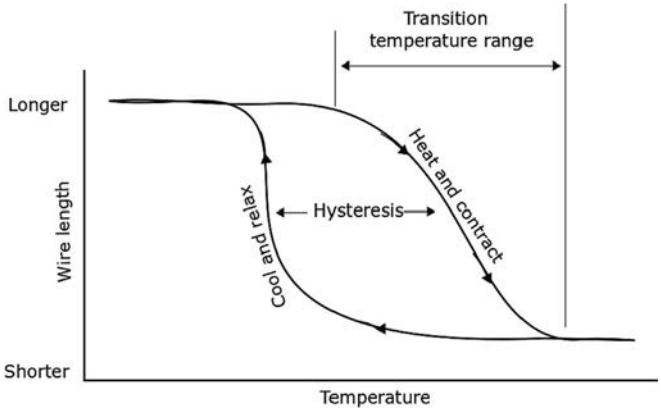

Fig. 1. The Characteristic curve wire length of a shape memory alloy as a function of temperature. When heated, the alloy contracts; when cooled, the wire can be manually relaxed and turned into any shape. There exist a transition temperature range as a result of hysteresis such that the wire does not immediately relax or contract at a set temperature value.

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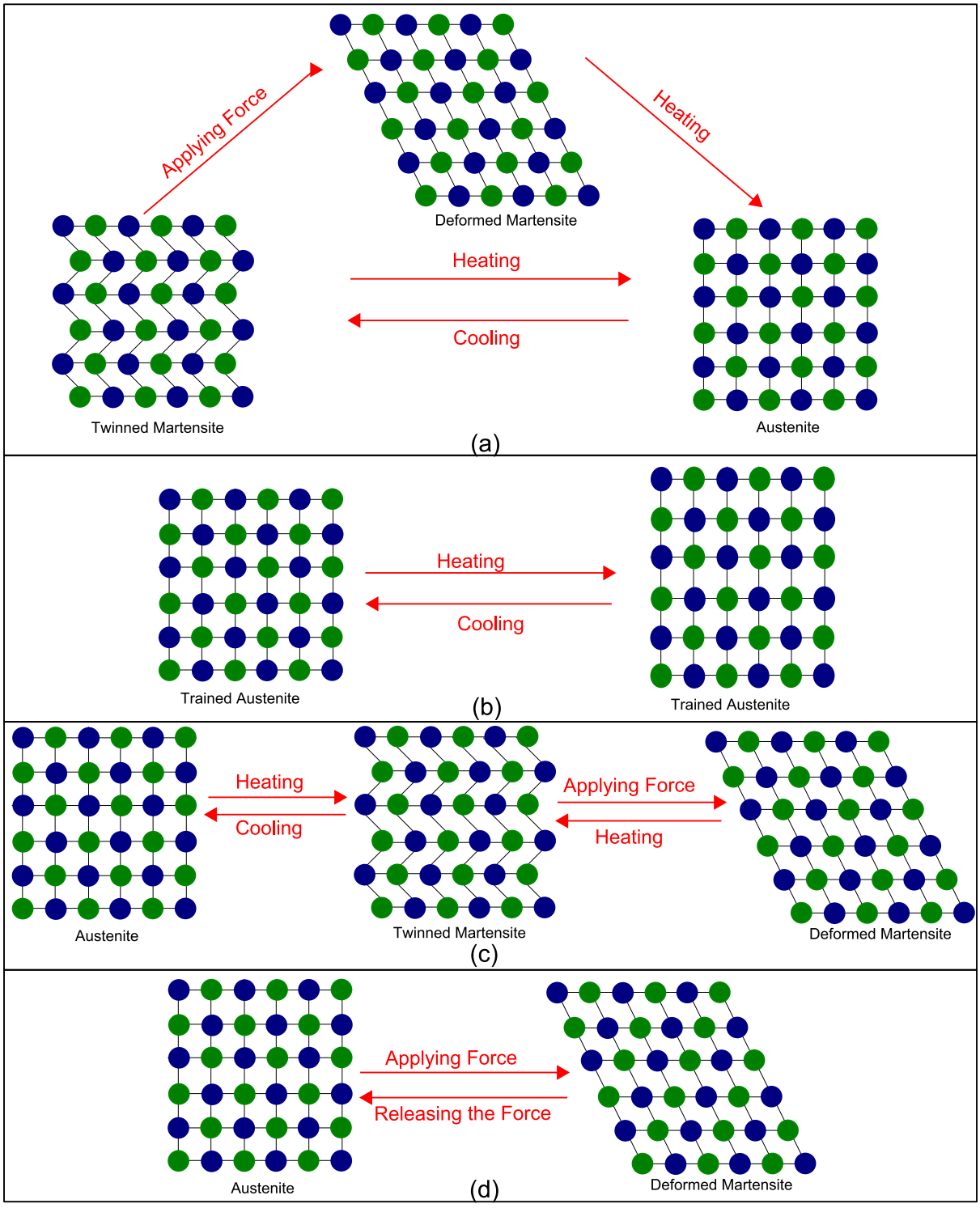

Fig. 2. The three different forms of Shape Memory Alloys are austenite, deformed martensite, and twinned martensite (a) A One-way Nininol alloy exists in the austenite form when heated; when the heat source is removed, the alloy exists in the twinned martensite form; upon the application of an external force to a cooled NiTi alloy, its form becomes deformed martensite; when heated either from the twinned martensite or deformed martensite form, it goes to its austenite form. (b) A Two-way SMA alloy exists in two different austenite states when heated and when cooled. (c) A Shape Memory Polymer exists in the three different forms. Only after heating (changes to twinned martensite) an external force to deform can be applied to reach the deformed martensite state. (d) A superelastic SMA exists in only the austenite and deformed martensite form; no heating is required, only an external force changes it to deformed martensite, the release of that applied forces causes it to spring back to its austenite form immediately.

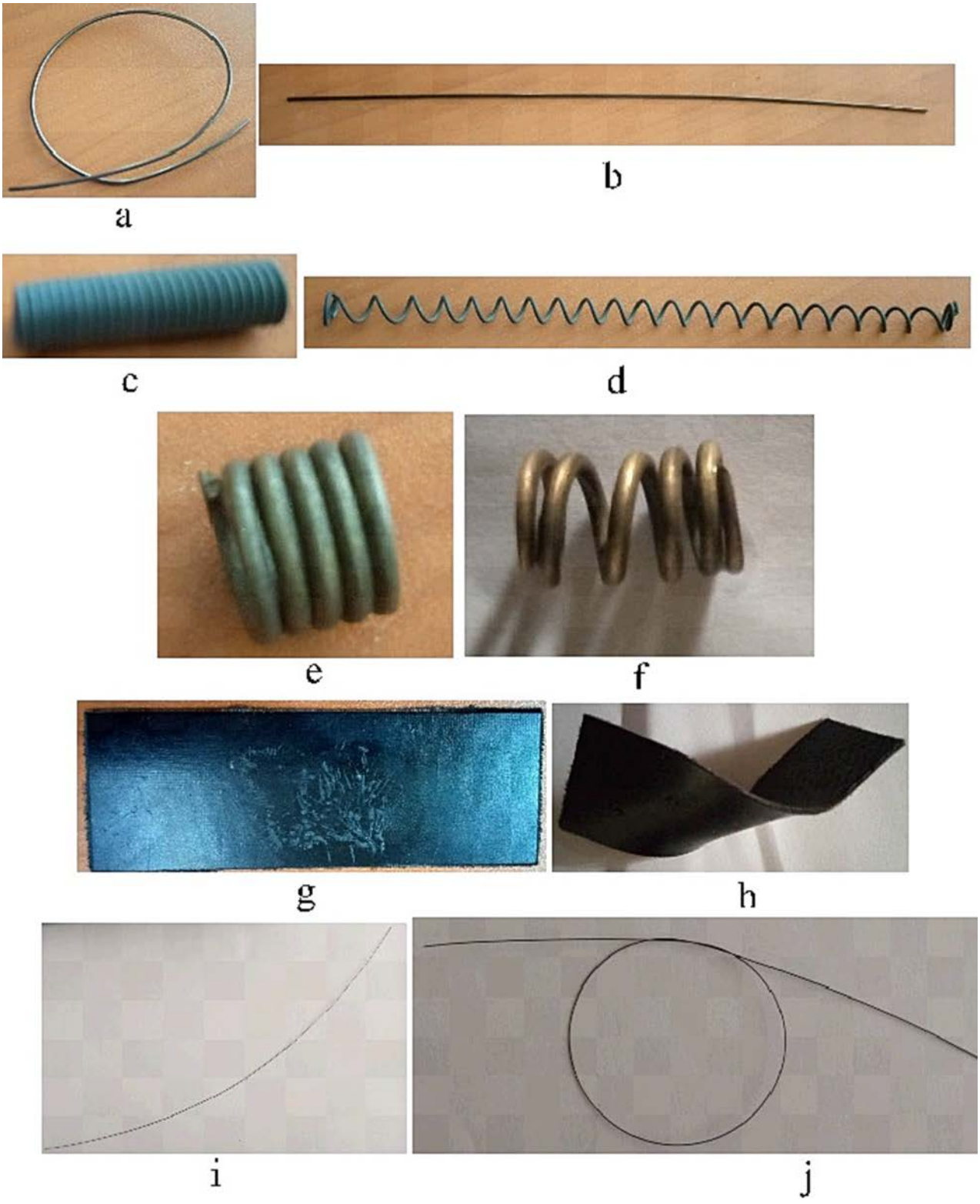

Fig. 3. (a) The SMA Nitinol wire is not actuated by an electric current and is bent to any shape or form. (b) The SMA wire in (a) is heated and straightens, and contracts by 3% of its original length. (c) The SMA Nitinol spring is in the form of a helically-wound spring; it is in its contracted form upon applying heat/electric current. (d) The Nitinol spring is relaxed and is manually stretched to two times its original length (c). (e) A two-way SMA spring exists in its contracted form when not activated by heat/electric current. (f) The two-way memory spring in (e) is heated by high temperature and exists in its stretched form. (g) A Shape Memory Polymer exists in its unactuated form. (h) When the Shape Memory Polymer in (g) is at high temperature or heated by electric current, it becomes pliable and soft and can be molded into any shape or form as shown, the molded shape is maintained even when the temperature of the polymer drops to room temperature, the polymer can be remolded by reheating. (i) An SMA superelastic wire exists in a straight form at normal temperature. (j) When the SMA superelastic wire in (i) is subjected to another state through the application of a force or constraint as shown, upon the removal of such force/constraint, it springs back to its original form of (i).

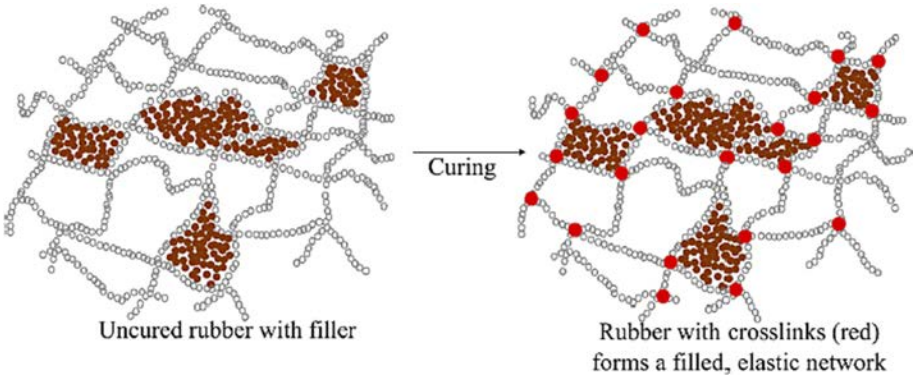

Fig. 4. When pigment is added and mixed with liquid rubber and cured, the rubber crosslinks with the pigment forming a filled elastic network that has both properties of the pigment and the rubber.

Fig. 5. A 150 mm nitinol wire is coated with a sky-blue microencapsulated thermochromic pigment achieved by impregnating liquid latex rubber with a sky-blue thermochromic pigment. The coating texture is coarse and uneven due to the use of the paintbrush method to coat the wire's surface.

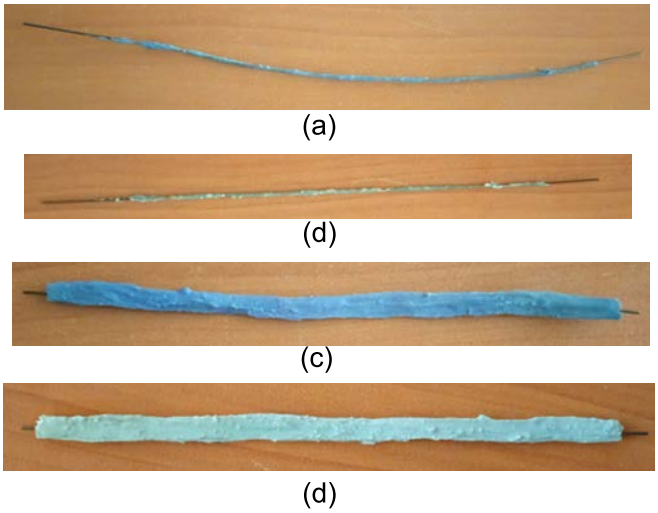

Fig. 6. The different types of color changing NiTi wires produced. (a) A 1 mm thick microencapsulated thermochromic pigment coated wire is sky-blue in color at room temperature of 27 °C. (b) When the wire in (a) is heated to between 40 °C – 60 °C through electric current, it immediately straightens, contracts, and changes color to amber, which indicates that the wire is at a high temperature. When the electric current is removed, the wire becomes pliable and gradually changes back to (a); at 15 min, the color change back to sky-blue is completed. (c) A 5 mm thick microencapsulated thermochromic pigment coated wire is sky-blue in color at room temperature of 27 °C. (d) When the wire in (c) is heated to between 40 °C – 60 °C through electric current, it immediately straightens, shortens, and changes color to amber, which indicates that the wire is at a high temperature. When the electric current is removed, the wire loses its contraction and gradually changes back to (c); at 25 min, the color changes back to sky-blue is completed.

Table 1
Physical and chemical properties of the thermochromic pigment.

Property	Description
State	Emulsion (Slurry)
Color	Sky-Blue
pH	5–6
Odor	Odorless
Boiling Point	100 °C
Specific Gravity	Water (1)
Vapour Pressure	30 mmHg
Solubility in water	Water Soluble
Evaporation rate	Ethyl-Ether (1)
Percent Volatility (by volume)	52%

Table 2
Physical and chemical properties of the latex rubber.

Property	Description
Form	Emulsion with 55% solids content (It is a rubbery solid when cured)
Appearance	Milky when in liquid form but translucent and amber when cured
Curing time	4–16 h in a warm, ventilated room. Curing time is affected by temperature and humidity. Warm, dry air is necessary for fast curing
Odor	Slight Ammoniacal
Solubility in water	Miscible
Solids Content	55%
Ammonia Content	0.3%
Viscosity	Non-viscous (500–1500 cps)
pH	10–11

CRediT authorship contribution statement

Victoria Oguntosin: Conceptualization, Methodology, Writing – original draft, Investigation, Writing – review & editing.

Data availability

No data was used for the research described in the article.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Further reading

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