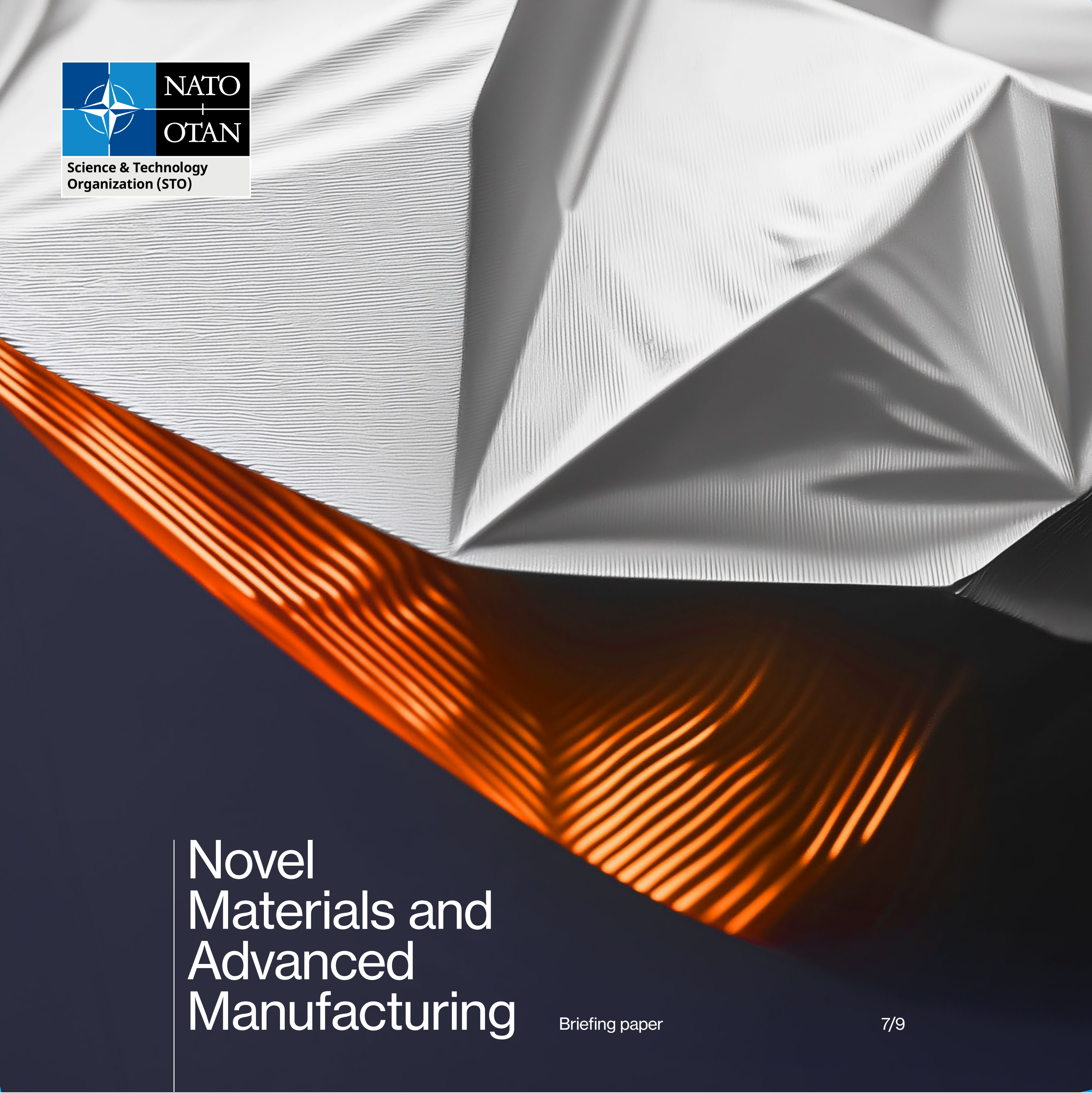
Science & Technology Organization (STO)



Novel Materials and Advanced Manufacturing

Briefing paper

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Research developments in novel Materials and Advanced Manufacturing have rapidly progressed in the past two decades, and will cause disruption in the next two, with 2D materials, additive manufacturing, unique designs, smart materials, nanotechnologies and biomanufacturing having a wide range of applications from electronics to clothing. This will lead to unprecedented designs, and provide environmentally-friendly, cost-efficient alternatives to current designs.

Implications

Economic Implications – With the increasing scarcity of rare earth minerals and global competition over access to them, novel materials could provide solutions for products critical to the development of key technologies. Moreover, additive manufacturing and biomanufacturing (both separately and combined) could revolutionise industries, including construction, electronics, consumer goods, food and pharmaceuticals, by securing supply chains, increasing flexibility, and reducing costs and production times. The range of economically transformative opportunities is enormous, mirroring that of the effects of AI in the cyber domain.

Military Implications – 2D materials, additive manufacturing (i.e. 3D printing), unique designs, smart materials, nanotechnologies and biomanufacturing will have a wide range of applications from electronics to clothing. New materials will facilitate unprecedented designs, providing environmentally friendly, cost-efficient alternatives to current designs.

Societal Implications – Additive manufacturing enables mass application of customised products, more localised production and simplified global supply chains. Standardised products can therefore significantly reduce prices and improve accessibility of sought-after, expensive items (especially healthcare products). Alongside novel materials, they can also drive large-scale sustainability gains like waste reduction and energy-efficiency increases in production and consumption.

Key Technology Areas

2D Materials – With the discovery of graphene in 2004, 2D materials – including novel polymers, nanoscale materials and metamaterials (not found in nature) – have a wide range of mechanical, physical, chemical and electrical properties not found elsewhere. For example, graphene is one of the thinnest, strongest and most stretchable known materials. This makes 2D materials particularly impactful, and potentially disruptive for aerospace, electronics, energy storage, camouflage, protection, weapon technologies, sensors and portability applications, etc.

Additive Manufacturing & 3D/4D Printing – 3D printing processes add materials in an iterative way to build objects from digital models. Significant research advances have been made in recent years and continue, including in the promising area of biomimetics (e.g. replication of biological structures). 4D materials are 3D prints that can transform under changing environmental stimuli (pressure, heat, humidity, etc.). Such materials hold promise for new designs or sensors, particularly in biomedical applications. The future of 3D/4D printing will include the synthesis, assembly and construction of materials down to the nanoscale, i.e. nanofabrication.

Biomanufacturing – The possibility of directly manipulating and engineering biological systems and their products has opened up new approaches and opportunities for the use of biotechnologies. Engineered biological agents (cells, proteins, fungi, etc.) can be used to assemble or build a wide range of products – from pharmaceuticals, organs, human tissues or leather and concrete – enabling unique manufacturing and large-scale production capabilities. Specialised biorobots or xenobots for nanoscale manufacturing are also at an early stage of development.

Technology Convergence

Artificial Intelligence (AI) and Quantum – AI, further boosted by quantum computing, will contribute to the design, development and manufacturing process of novel materials with unique properties, and also the direct manipulation of both biological and chemical reactions. Quantum sensors will also improve our understanding of novel materials' performance and behaviour.

Energy and Biotechnologies – Biomimetic designs inform the creation of novel materials, as well as new (bio) manufacturing processes and applications of synthetic biology. Examples include the creation of novel synthetic or modified biological components or systems that can be (3D) bio-printed (e.g. organs, skin etc.), or the development of multicellular biosensors, biofuel energy systems or novel battery technologies.

Space and Hypersonics – Lighter, stronger and more durable novel materials and the ability to manufacture them will enable the development of new space launch capabilities, satellites and sensor systems, as well as hypersonic weapons and uncrewed systems that can operate at hypersonic speeds. This will increase the overall cost-effectiveness and durability of space assets and hypersonic systems, while improving operational effectiveness.