Centre for Joint Warfare Studies

EVENT REPORT

SEMINAR REPORT ON ADVANCED MATERIALS FOR DEFENCE & AEROSPACE

ORGANIZED BY CENJOWS & IMR

22ND NOVEMBER 2023

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The Centre for Joint Warfare Studies (CENJOWS), in collaboration with Indian Military Review (IMR), hosted a conference on "ADVANCED MATERIALS FOR DEFENCE 2023" on 22 November, 2023. The event was conducted in New Delhi's Manekshaw Centre. Prominent panelists in the conference comprised senior serving members from tri-services, representatives from DRDO, IIT and organisations. The seminar offered an environment for the industry to interact with the armed forces and engage in sharing of knowledge along with expectations of the user. The seminar was conducted in five sessions. The essential aspects from the seminar are covered in succeeding paragraphs.

SESSION 1: INAUGURAL SESSION

Lt Gen Sunil Srivastava, AVSM, VSM (Retd), Director CENJOWS**, felicitated the speakers, panelists, attendees, and other serving as well as retired officers from the three services in his welcome address. In is customary opening address of the seminar's he emphasized on the importance of critical and advanced materials and its supply chain across the continents and how the recent conflicts in Europe and middle east has affected the availability of special materials. Contemporarily our country has set in motion very important policies, on the advance and special materials keeping our immediate neighbours in the north and the west in perspective. He highlighted importance of Advance materials in weapon platforms to achieve the asymmetric advantage over our adversaries. As a user we always desired to have effectiveness, reliability, superior size to weight ratios, sustainability to adverse weather conditions in our weapon platforms and war equipment to be categorized as smart weapons and equipment. Nano-materials, Meta - materials, multifunction materials, and biomimetic materials are all smart materials which are being leveraged to have supremacy in the battlefield. Countries like United States, Australia, France, Germany, Japan, have got critical material strategies and policies. We are still yet to announce a critical materials strategy or policy.

Our country spent close to $2 billion worth of imports of advanced materials every year and majority of this comes from a potential adversary which is an issue of great concern. We have indigenized most of our systems but the special materials for these systems are being imported. We need to be conscious as to how we get self-reliant for semiconductors and critical material. The Mineral policy of 2020, has already assured a lot of corrective policy measures. The MMDR Act of 1957, Mines and Minerals Development and Regulations Act, a very sensitive act as far as mining is concerned, has been amended twice recently as a result 30 critical minerals have been identified and opened up for auction to the private sector. Even lithium, have now been deregulated. . A Rare Earth Permanent Magnet Plant, the first of its kind, has also been set up near Patna adding up to our capabilities. For Global partnerships, we are now engaged with the outside world through ICET, Initiative on Critical and Emerging Technologies with the United States. We've also signed the Mineral Security Partnership this year, with US and 12 other entities including EU. We've also inked a Critical Mineral Investment Partnership with Australia. We have already signed MOUs to engage with Chile, Argentina, Australia on getting lithium, cobalt and other special metals and to translated this into action, all the stakeholders present here for the seminar will brain storm today.

Dr Samir V Kamat, Secretary Dept of Defence R&D & Chairman DRDO, delivered the inaugural address. He emphasized that materials, technologies supports almost all defence systems and to have significant improvement in the performance of the defence system, better materials with superior manufacturing technologies is required to be put in place. Unfortunately, we have not paid much attention to this important field. If we want to achieve our Honorable Prime Minister's dream of Atma Nirbhar Bharat and technology leadership in this Amrit Kaal, we have to pay greater attention to this stream of technology. Broadly materials can be divided into structural and functional materials, based on their roles. There are materials which perform the load bearing task for any weapon platform and there are materials which perform certain functional role of specific nature. Structural materials are materials such as steels, aluminum alloys, titanium alloys, polymer matrix composites, ceramic matrix composites. Whereas functional materials are semiconductors, silicon, gallium arsenide, gallium nitride, permanent magnets, stealth materials which provide a certain functional role to the system.

We have been fairly strong in the structural materials however manufacturing of functional materials remains a grey area for us. We were left behind in the silicon race in the 70s. For the new semiconductor materials developed for high power electronics such as silicon carbide, we have to ensure that we do not miss the opportunity. If we want to design a hypersonic missiles, we need to first develop the scramjet propulsion and to develop scramjet propulsion, we need to develop materials which can withstand those high temperatures and to achieve this we need to look at niobium alloys, and nickel based super alloys with cooling channels. Developing materials for defence and aerospace has several challenges. Some of these challenges are low volume and sporadic orders for the industries, stringent requirements for qualification and certification exponentially increasing the overall cost. However, the most significant challenge is the long development cycle for any material development. The design cycles for new weapon systems are shrinking. They are now down to about 4 to 5 years where as the new material development cycle is 10 to 15 years. So it is extremely challenging for a designer to starts designing a system to decide which material he should use. Lots of attempts internationally are now being made to see how this new material development cycle can be shrunk. Efforts are being made and over the next 10-15 years, we will be able to make some progress in lot of fields. The other initiative which is happening globally is known as the materials genome initiative which is a more hybrid approach.

It is the materials modeling approach including rapid experimentation approach and also using artificial intelligence and machine learning approach. Lot of material data has been collected over the years and using AIML tools, it is possible to get some insight into what should be a material or what should be the composition of a material or what processing should be used to achieve the desired outcome. As a nation we must have a more collaborative approach where academia, R&D institutions as well as industry work together to achieve this goal. The important thing that we also have to look at is the manufacturing because it is easy to make materials in the laboratory when you have to do it in a few grams or few kgs. The challenges start when we have to scale up and make it at an industrial scale. The challenges are not only technical in nature but also techno commercial because unless the volumes are large, the cost becomes high. The issue of the infrastructure required for materials manufacturing is also very costly. All these are being addressed with right intent in a proactive manner.

The Keynote Address was given by Lt. Gen Manjinder Singh, YSM, VSM, SM, DCIDS (PP&FD), HQ IDS. He highlighted the overwhelming reliance on China for critical hardware and special materials and other nation needs to address this issue. The inclusion of fabrication and production of semiconductors through the new semiconductor policy is a welcome step in this regard. Dwelling upon the broad application of 3D painting, additive manufacturing from its initial beginning in the commercial house building and allied industries, 3D printing has come a long way and its application in increasing in domains of medical technologies to space. The speaker highlighted the statement of Deng Xiaoping wherein he once remarked that crude oil being synonyms to Gulf similarly rare earth elements to China. He brought to fore the aspect of ICT industry of computers and mobiles seeking safer offsets of conductors, semiconductors industries outside China's sphere of influence. This is where India stands to gain. The West's over-independence on China for rare earth elements has exposed the critical fault lines that are now being addressed globally. Tech giants like Apple, Boeing, Lockheed Martin are tightly coupled with China on the relevance of advanced Materials, semiconductors and rare earth elements and trying to decouple the same. India must move into the semiconductor space with attractive investments opportunities to create a credible alternative to China's manufacturing industries.

7. Tata Group's acquisition of the Bristol plant for manufacturing chips and iPhones in India demonstrate our intent to harness the opportunity of decoupling from China. Modern war demands fighting and winning with indigenous solutions. Adoption through innovation of critical emerging technologies such as advanced materials, rare earth elements, composites and semiconductors are the way forward for our nation and to achieve this public, private sector industries, academia, and defence forces needs to collaborate frequently at all echelons. The government is putting policy and procurement measures in place, requisite hand-holding of industry, exploring this space is need of the hour for capability building and obviating foreign dependencies in this field.

Maj Gen Charanjit Singh Maan, VSM Additional DG Army Design Bureau highlighted the perspective of a user. He mentioned that the quality, type, composition of material is insignificant for the user. What matters to the soldier is that it should be able to perform the desired task. He highlighted the kinds of advanced materials which are required for land forces applications. He mentioned about the importance of higher strength to weight ratio because it leads to overall weight reduction for the soldier's equipment and weapons. He also emphasized upon High thermal stability, enhanced electrical conductivity, strength performance, higher sensing capabilities, and energy storage along with, durability factors of the equipment which impacts its overall configuration for fighting a battle. Speaking about each of these parameters he mentioned that for any land system, it should be lightweight, flexible with higher performance to improve the agility for a soldier and afford maneuverability to the platform. All efforts should be made to reduce the overall weight of the load table of a soldier. Even two kgs of helmet is also quite a bit for him during a combat. Similarly, the bullet proof jackets or vests should also be as light as the combat dress worn by the soldier and be as flexible and protective in nature. The materials used in unmanned aerial systems, directed energy weapons like Laser, Microwave should be able to withstand high temperature. Special batteries which are lightweight and compact should be the order of the day. Conformal sensors and integrated circuits should be small and light with improved aerodynamic.

The communication systems have to be lightweight high performance antennas. EMI shielding should also have high signal integrity and low loss. Similarly, counter measures systems should also light weight high portability with ability to detect stealthy assets. For example, radar systems equipped with advanced signal processing algorithms and integrated with Meta-material based antennas should be able to dissipate the effectiveness of strength materials by unique electromagnetic properties. The requirement of keeping the troops warm at high altitude regions should use materials which can withstand the wear and tear of weather and extreme fluctuation of temperature. With advanced materials we can achieve a much more efficient habitat system. He highlighted certain initiatives, projects which are under consideration for eg protective spray on coatings and paints, especially for the unmanned aerial systems protecting them from high power laser weapons, the nano caffeine absorber coatings for different kinds of defence applications ceramic protection solution for armor protection, low cost sensor technology to detect different bio-warfare agents, Smart thickening, fluid based, ultra resilient, adaptive kinematic soft rubber armour, sub-zero temperature lithium ion batteries for supporting high altitude operations, energy harvester assisted Power Bank for mobile equipment which shows a comprehensive integration of Advanced Materials across diverse domains within the defence forces.

The industry perspective was given by Col KV Kuber, Director Defence and Aerospace, E&Y. He highlighted that Ukraine is an important global producer for some of the primary raw materials, titanium, gallium, manganese, iron, uranium and current crisis in Ukraine has affected their availability. Russia and Ukraine lead the global production of metal like nickel, copper, iron ore. They're involved largely in exports of neon, Palladium, platinum. Russia is a leading player in the titanium and accounts for 13% of the world share. Western aerospace companies are heavily reliant on Russian titanium. Boeing purchase 1/3 of its titanium requirements from Russia, Airbus purchase about 50% and Embraer entire supply is dependent on Russia. Similarly, the Indian suppliers like Saffron Rolls Royce source 50%, 20%. Of the titanium from Russia. India, also imports Lithium, cobalt, nickel, vandium, niobium, germanium in large quantity from China, Chile, Russia, Australia, South Africa The global aerospace and defence materials market was at 36.42 billion in 2021 and it's expected to grow about 67.42 by 2025. During the COVID, the cost of these special materials increased by 30%.

The speaker highlighted that China has imposed export restrictions on gallium, gallium and germanium in response to Washington sanctions exposing the vulnerabilities of western countries on dependence on China for critical raw materials. Referring to Turkey the speaker mentioned that she does not have certifications. They follow the supply and demand concept along with user requirements and they are one of the largest exporters of special materials. Certification is definitely a time consuming factor and sometimes frustrating. As far as China's ambitious Belt Road initiative is concerned they are proactively engaged with African Union Countries and Australia to meet their burgeoning demand. China is diversifying its supply sources by investing in Africa and Australia. The western countries are still trying to adapt to the situation. We have placed certain materials in the positive lists of indigenization which is highly significant for the industry. He further highlighted that a raw material available in India, should be banned for import. The speaker concluded by enunciating the government of India introduction of policy on critical minerals in June 23 enabling the private players to explore and mine these minerals. This is a defining moment for the industry.

SESSION 2 : ADVANCE MATERIALS FOR AEROSPACE

Session 2 was chaired by **Air Vice Marshal Yalla Umesh VSM** and the eminent panelist were **Prof Ravi Shankar Kottada**, **Shri Alok Singh Chauhan** and **Mr Srinath Ravichandran.** Professor Ravi commenced the session by explaining the aspects of latest technologies in preparation of special advanced materials. He highlighted that Addictive Manufacturing is the "process of joining materials to make parts from 3D model data. Elaborating on these methods he explained the process of Metal Additive Manufacturing (AM) by Laser Powder bed fusion (PBF), Direct energy deposition (DED), Sheet metal lamination method.

Laser Powder Bed Fusion (LPBF) method: Powder is used as feedstock & laser as the energy source. A high purity argon atmosphere is maintained inside the chamber. It offers better dimensional accuracy (up to 10µm) and surface finish (up to R_a = 3.5 µm). A high-purity argon atmosphere is maintained inside the chamber during this process, likely to prevent oxidation or other reactions that could affect the quality of the metal parts being produced. It achieves better dimensional accuracy (up to 10 micrometers) and surface finish (up to a roughness average, R_a, of 3.5 micrometers).

Chessboard Strategy: Using a chessboard strategy results in lesser niobium (Nb) and molybdenum (Mo) inter dendritic segregation. The distribution of these elements within the alloy improving its overall properties.

Re-melting vs. Chessboard: Re-melting exhibits higher strength, which indicates that the process of melting the material again may lead to an increase in mechanical strength.
Chessboard exhibits higher ductility, suggesting that this strategy provides the material with more ability to deform without breaking. Additionally, the chessboard strategy is noted to exhibit higher creep rupture life, which means the material can withstand long-term exposure to high stress and temperature without failing.

Melt Pool Boundaries: Melt pool boundaries act as crack initiation sites during creep deformation. Melt pools are areas where the metal has been melted during the manufacturing process, and their boundaries can be weak points that lead to cracking under certain conditions, such as creep, which is slow deformation under stress at high temperature.

The 2nd speaker **Mr Srinath Ravichandran** from AGNIKUL COSMOS covered the essential aspects of AGNIBAAN which is an "Agnikul's mini launch vehicle." The aspects covered were as follows:-

(a) Customization and Efficiency: The vehicle is dedicated and fully customizable for launching small satellites. It offers a 40 times faster launch turnaround which is a significant improvement in launch scheduling. The vehicle is linearly scalable from carrying 30 kg to 300 kg, indicating cost-effectiveness for various payload sizes which is 10 times cheaper. The engines are named Agnite and Agnilet. Each Agnite engine can produce 25kN of thrust at sea level and can be configured with 4, 5, 6, or 7 engines. The Agnilet engine produces 8kN at vacuum.

(b) Physical Characteristics: The vehicle has a mass of 15 tons at launch. It stands 18 meters tall and has a diameter of 1.3 meters which is a 2-stage vehicle. Agnibaan SoTeD (Suborbital Tech Demonstrator) is a vehicle designed to validate key technological aspects of Agnikul vehicles. Its first flight is scheduled for November or December 2023. It includes all the avionics, telemetry, and guidance systems that would be used in commercial launches.

The third speaker **Shri Alok Singh Chauhan** cover the aspects of Supper alloy casting technology for aero gas turbines engine applications. He covered the following aspects.

(a) 3D printing as Manufacturing Technique in Aerospace. Essential aspects covered were Complex Geometries 3D printing enables the creation of intricate and complex shapes that are challenging for traditional manufacturing methods, allowing for the design of optimized and lightweight structures for launch vehicle components. Rapid Prototyping and Iteration It offers the ability to quickly prototype and iterate designs, which is crucial in aerospace industry. The technology provides fast and cost-effective production of prototypes, enabling engineers to test and refine components rapidly. Mass Reduction In space missions, where weight is a critical factor, 3D printing facilitates the design of components that are lightweight while maintaining structural integrity. This reduction in mass contributes to increased fuel efficiency and payload capacity. Customization for Specific Missions Each space mission may have unique requirements, and 3D printing permits the customization of components based on those specific needs, providing flexibility in design and production. Consolidation of Components The technology can consolidate multiple parts into a single, complex structure. This reduces the number of individual parts, streamlines assembly, and potentially minimizes points of failure

(b) Application of Copper in Aerospace. The speaker elaborated on the different uses of copper alloys in the aerospace industry due to their favourable properties: These properties are Heat Exchangers where, due to their thermal conductivity, copper alloys are used in heat exchangers. They are crucial for managing extreme temperature variations and have applications in spaceflight. In Fuel Systems Components Copper alloys are utilized in the construction of various components in aircraft fuel systems. These include parts like fuel lines, fittings, and valves. They are chosen for their corrosion resistance and ability to withstand high temperatures.

(c) Engine Components: Certain copper alloys are used in manufacturing engine components such as bushings and bearings, where resistance to wear and corrosion is essential. Copper-nickel alloys are noted for their good corrosion resistance in marine environments and can be used in aircraft engines.

(d) Landing Gear Components: Copper alloys may be used in some landing gear components where a combination of strength, wear resistance, and high stress resistance is required. Beryllium copper alloys, for example, are known for their high strength and wear resistance.

(e) Electrical Wiring and Connectors: Copper is an excellent conductor of electricity, making it ideal for use in electrical wiring and connectors in aircraft. It is used in electrical systems of aircraft for transmitting power and signals. The high conductivity of copper ensures efficient transmission of electrical power, and its ductility allows for the production of complex wire and electronic components.

Covering the canvas of Challenges in 3D printing of Copper & Smart alloys the speaker covered the followings pertinent issues:-

(a) High Thermal Conductivity: Copper alloys have high thermal conductivity, which can cause issues during 3D printing such as rapid solidification and residual stresses, potentially affecting the dimensional accuracy and integrity of the final printed part.

(b) Oxidation Sensitivity: Copper is prone to oxidation when heated, which can occur during 3D printing. This can negatively impact the mechanical properties of the final part. Careful control of the printing environment, such as maintaining a low-oxygen atmosphere, is essential to mitigate this challenge.

(c) Printability Issues: Copper alloys' properties can make achieving optimal printability challenging. Issues that may arise include bailing or electron beam deflection, and preventing these requires careful optimization of the printing process.

(d) Thermal Stresses and Cracking: The high thermal conductivity of copper alloys can result in rapid cooling rates, leading to thermal stresses and the potential for cracking in the printed part. Proper refining of the process is necessary to manage this.

The chairperson concluded by highlighted that all super alloys may not be meant for manufacturing. While super alloys are highly specialized materials known for their exceptional mechanical strength, resistance to thermal creep deformation, good surface stability, and resistance to corrosion or oxidation, they might not always be suitable for use in manufacturing processes.

SESSION: 3 - ADV MTRLS FOR LAND SYS, MSLS AND NAVAL AAPLCATIONS

The session was chaired by **Rear Adm K Srinivas (Asst Chief of Materials (Dockyd and Refitting), Naval HQ)** and Speakers were **Cdr BK Singh, DND(SDG)**, Naval HQ and **Lt Col Kunal Tagunde,** CME, Pune. Chairman opened the session by highlighting importance of advance materials in manufacturing of battle ships for the Indian Navy. He emphasized that advance materials will play strategic role in security structure of armed forces in future, not only in development of platforms of Indian Navy. The Indian Navy uses specific material for ship building e.g Advance steels for hulls for ships. Materials used for Hulls is completely indigenous, highlighting Atam Nirbhar Bharat success story. These materials are being developed by DRDO through integral research fraternity. Composite materials used in Ship building to reduce weight and increase stealth features are constantly being improved locally. To highlight self sufficiency of country in the field and specialisation, it was mentioned that Vizag Dockyard uses 22 different types of steels for various manufacturing activities.

Indian navy's requirement in future will be met completely by indigenous resources. Special emphasis on Research and development by DRDO e.g Fuel cells, Coating, Thermal conductors, Alloys etc were also highlighted

Second Speaker, Cdr BK Singh spoke on "Special Materials for Ships and Submarines building" and highlighted following aspects:-

(a) Information about structural materials used for ships/submarines and their types of materials used High strength low alloy steels for hulls, Titanium and Cu-Ni alloy for pipes, Aluminum Alloy for Super structures, Composites materials for hull of small crafts, Cladded steel for interface structure. Covering the canvas of material failure he mentioned that the material failure primarily occur in form of fracture/ fatigue/ creep.

(b) He highlighted the Desired strength of materials by explaining the factors of Yield strength, Resistance to brittle fracture, Toughened, Good ability to get welded. The speaker emphasized on developing indigenous capability. Constant efforts are going on developing High strength steel. He mentioned about the Way Ahead in which he mentioned Development of futuristic materials with improving qualities like Steels with Yield Strength of 1000 MPa, Metal fiber composites and Biometric Hull the speaker spoke about Challenges being faced in Titanium Welding.

23. **Third Speaker Lt Col Kunal Tagunde** spoke on "Latest developments in Impact absorbing body armor" and highlighted aspects of improvements in Body Armour. Emphasizing on Historical perspective, the speaker mentioned the mismatch in requirements vis a vis availability for ground troops of Indian Armed forces. Highlighting on the Service Requirements he highlighted the aspects of Flexibility, Ergonomics, Latest trends, New and innovative materials being developed e.g Fiber, CT, Carbon Nano etc. He briefly covered the Initiatives By CME, Pune on project PADAM KAWACH

<u>SESSION4 : SMART & FUTURE MATERIALS/REAR EARTHS & SEMICONDUCTORS</u>

24. The session was chaired by **Rear Admiral Deepak Bansal VSM, Retd** and the speakers were **Shri Anuttam Mishra**, **Dr Kingsuk Mukhopadhyay**, **Dr Apurba Sinhamahaptra** and **Sh KNS Pavan Kumar.** Rear Admiral Deepak Bansal highlighted that there is a need to devise a strategy to develop the ecosystem related to chips as well as special materials by bringing together all stake holder including the Govt. He mentioned that Rare Earths are in abundance however these oxidised materials are rare because most deposits are of low in concentration and takes lot of efforts to process it.

The first speaker **Mr Anuttam Mishra**, commenced his talk by highlighting the efforts of DAE in last 40 years. He highlighted that Rare earths are a group of 17 chemical elements which are used to produce useful high tech products. Seven minerals are available in India which are processed by Rare Earths. Out of these thermal applications materials have been provided to defence and BARC. Though the Rare Earths have offered finished material like Phosphorous catalyst etc to the civil industry for exploitation, it has not found much success. There are few mining sites with limited mining capability, hazardous residue, long gestation period, highly capital intensive, economy of scale due to low consumption. Most materials are highly radioactive and hence need high order of safety measures in their handling.

Dr Kingsuk Mukhopadhyay, Scientist DMSRD, DRDO spoke about Thermally Conducting Light Weight Nano composite based Structures for Torpedo Propulsion. Electrically insulating vis-à-vis thermally conducting nano composite based rotors, stator and end covers have been fabricated for torpedo propulsion motor as per the design provided by Naval Science & Technological Laboratory (NSTL), Visakhapatnam with lower weight, higher viscoelasticity and dimensionally stable compared to contemporary metal alloys. The end covers were successfully completed field trial at NSTL Vishakapatnam and other components are still under trial for making propulsion motor with advantages of stealth, power density and quality of torque. Portable drinking water using porous nano fibre membrane for the NDRF and CRPF have been successfully developed. One of the major challenges for portable water filtration is rate of filtration due to insufficient gravitational pressure. A mitigation technology in compact area is developed by DMSRDE using porous nano fibres which don't use any chemical or electrical power for purification. Pocket filtration cartridge has a unique feature of air droppable characteristics which enables mass scale supply of drinkable water during natural calamities. Pocket filtration cartridge could fit into plastic water/cold drinks bottle of standard nozzle size has been developed using nano fiber-based membrane and changeable pre filters for prolonged uninterrupted supply of potable water.

DMSRDE has prepared unique SSG which shows the change in viscosity as a function of shear force and holds a great promise for damping and shock energy dissipation. Its Applications is in preparation of Flexible gel filled polymeric scaffolds/laminated composites for efficient absorption of low to medium velocity impact. Besides this DMSRDE has successfully developed modular Bullet Proof Jackets (BPJs) to provide 360-degree protection as per the laid down GSQR.

Shear Stiffening Gel (SSG) and its Laminates for Impact Resistant Applications. Shear thickening fluid (STF) is the non-Newton fluid which increases its viscosity when the shear rate exceeds a critical value. Shear Stiffening Gel (SSG) shows more stable performance, and it is easier to store compared to its fluidic form which helps to overcome the problems of particle sedimentation and liquid volatilization. Flexible gel filled polymeric scaffolds/laminated composites have been prepared for efficient absorption of low to medium velocity impact.

Functional Materials for Radar Absorbers are Dielectric materials which impart dielectric polarization losses whereas Magnetic materials Imparts magnetic losses Ferrites, carbonyl iron, iron silicide. He also informed the audience about the development of Camouflage Systems, Synthetic Camouflage Net (SCN): 1000 SCN each for Snow Bound Area (SBA) & green belt area produced and supplied to army. These nets are accepted for introduction into services. Radar Absorbing Camouflage Net (RSCN) were found effective against Visual, IR and Radar Surveillance. Multi-Spectral Camouflage Net (MSCN): Effective in Visual, NIR, TIR and MW bands (8-40GHz) Multispectral Personnel Camouflage Equipment (8-18GHz) (MSPCE): Effective in Visual, NIR, TIR and MW bands. Mobile Camouflage System (MCS) were effective in Visual, NIR, TIR and MW bands (8-18GHz)

Besides this Multispectral Personnel Camouflage Equipment consists of Suit, Poncho & Screen to provide Multi-Spectral camouflage performance in VIS, NIR, TIR and MW regions and Mobile Camouflage System (MCS) provides protection to Armoured Vehicle (T-90) against visual, NIR, Thermal and Radar detection under static & mobile conditions have also been developed. DMSRDE successfully developed Boot Anti Mine Infantry (BAMI) for Infantry troops Indian Army and CAPFs. It is Combat/ Ammunition design and provides protection against 35 g APNM M-14 Mines by attenuating the peak-over pressure. The other equipment developed by DMSRDE are as follows:-

(a) NBC SUIT PERMEABLE Mk- IV. New generation suit based on State-of-the-Art technology of activated carbon spheres, for protection against NBC warfare agents especially hazardous chemicals.

(b) NBC GLOVES Mk I. It is to be used for protection of hands in NBC contaminated environment especially from hazardous chemicals. The surface of thumb, fingers and palm is serrated for better gripping.

(c) Advanced Version of Chemical Protective Gloves. These gloves are to be used for protection of hands in NBC contaminated environment especially from hazardous chemicals. The surface of thumb, fingers and palm is serrated for better gripping.

(d) CBRN Gloves Mk-II .CBRN Gloves Mk-Il are integral part of chemical protective clothing for protection of hand against chemical warfare agents (CWA).

(e) CBRN Over boot Mk-// CBRN Over boot Mk-ll are integral part of chemical protective clothing for protection of foot against chemical warfare agents.

(f) NBC Face let Mask Mk II (ACF based). Provides interim protection in NBC contaminated environment. These Face masks are under development.

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Dr Apurba Sinhamahapatra, from CSIR covered extensively the Shape memory Alloys as the smartest materials. He highlighted that Shape Memory Alloys (SMAs) are fascinating materials known for their unique ability to recover their original shape after undergoing deformation. This remarkable property is due to a reversible phase transformation between austenite and marten site phases in response to temperature changes. SMAs have a shape memory effect, allowing them to remember" their pre-deformed shape under specific temperature conditions, making them useful for precise and reversible shape changes. The alloy called Nitinol named after Nickel Titanium Naval Ordinance Laboratory, displayed the ability to return to a predetermined shape after being deformed when exposed to heat. Though discovered in 1962, it has found greater applications in the medical devices, including vascular stents, guide wires, and orthodontic devices. Currently, its applications have gone beyond medical to include aerospace, robotics. SMA's have two stable phases namely The high-temperature Austenite and Low temperature Martensite which is formed by a combination of self-accommodated martensitic variants, in two forms Twined and De twinned.

He also apprised the audience on types of Shape Alloys. There are two types of Shape Alloys One Way Shape Memory alloy which remembers only one shape. The material can get deformed at lower temperature and can attain its predefined shape via heating. The second material remembers two different shapes, one at a lower temperature and other at a higher temperature. Even a slight increase in the higher temperature makes the Shape memory Alloy to forget its shape. Iron and copper based SMA's such as FE-Mn-Si and Cu-Zn -Al are commercially available and cheaper than NiTi. Other Characteristics are **Super elasticity**, making them useful in biomedical devices and actuators. **Temperature-Induced Phase Transformation** SMA's behaviour is influenced by temperature-induced phase transformation between austenite and marten site, which can be customized during alloy fabrication for specific application requirements. **Damping Capacity** of SMAs is beneficial in reducing vibrations and enhancing the overall stability of structures. **High Strength and Lightweight** like material Nitinol is known for its high strength-to-weight ratio, making it suitable for various engineering applications.

Shri KNS Pavan Kumar from YSL Smart Materials DRDO covered the topic of Applications of Smart materials for future Military Electronics Applications. He informed the audience about various applications of special and smart materials. Some of the applications are as follows:-

(a) **Actuators and Adaptive Structures**: Nitinol's reversible phase transformations make it ideal for aerospace actuators, allowing controlled shape and length changes, enabling adaptive structures to respond to different flight conditions.

(b) Deployable Structures: Nitinol is utilized in aerospace for developing deployable structures, which can be compactly stored during launch and deployed in space, especially for satellite applications.

(c) Aircraft Components: Nitinol is used in aircraft components like wing morphing actuators to enhance aerodynamics by ensuring structural integrity despite large deformations.

(d) Space Mechanisms: Nitinol's resilience and adaptability make it ideal for space mechanisms, particularly in devices like hinges and latches, which require reliable functioning in harsh conditions.

(e) Satellite Components. Nitinol, a lightweight and reliable material, is utilized in satellite components like antennas, solar arrays, and deployment mechanisms due to its ability to withstand harsh space conditions.

(f) Aircraft Engine Components: SMAs can be employed in components of aircraft engines, such as variable inlet guide vanes. These vanes, made from SMAs, can change their shape to control the airflow entering the engine. This can optimize engine performance under different operating conditions, improving fuel efficiency and overall engine efficiency.

(g) Self-Repairing Textiles: Smart materials, can be used in the development of self-repairing textiles for military uniforms. If the fabric is damaged, SMAs could be designed to revert to their original shape, closing small punctures or tears. This feature increases the longevity of the uniform and reduces the need for frequent replacements.

(h) Enhanced Load-Bearing Equipment: Load bearing equipment, such as backpacks and harnesses, be designed with SMAs to adapt to the wearer's movements. The straps and load distribution components could adjust their tension based on the soldier's posture and movements, improving comfort and reducing the risk of fatigue or injury.

(j) Adaptive Camouflage Cloaks: Integrating SMA's into camouflage cloth could provide soldiers with an adaptive and chime like abilities. The cloak could change its colour and pattern in response to the surrounding environment, enhancing the soldier's ability to blend into a different terrains and environment.

(k) Biomechanical Support Systems: SMA's can be used in exoskeletons or Biomechanical support systems integrated into military uniforms. These systems could provide additional strength and support to soldiers during physically demanding tasks. The SMAs would adapt to the user's movements, enhancing agility and reducing fatigue.

(l) Adaptive Control: MA actuators in the design of adaptive surfaces for aircraft and drones surface, such as ailerons can change their shape in flight conditions, improving their stability. This adaptability is especially valuable in operational environments.

(m) Morphing Wings of Aircraft: SMA can be incorporated in the wing structures of aircraft to create morphing wings. These wings can change their shape in flight to optimise aerodynamics and performance. The ability to adjust the wing geometry can enhance manoeuvrability and fuel efficiency, providing a tactical advantage for military aircraft.

(n) Deployable Structures: SMAs can be integrated into mechanisms for deployable structures, such as antennas or shelters. The SMA actuators allow for compact Storage during transportation, and upon reaching the destination, the structures can be deployed by applying the appropriate stimulus, such as heat. This is particularly useful for military operations where rapid setup and teardown of equipment are crucial.

(o) Temperature -Responsive Uniforms: Military uniforms incorporating SMAs could adjust their properties based on the soldier's body temperature. For instance, the fabric could contract to provide better insulation in cold environments and expand for improved ventilation in hot conditions. This adaptive feature enhances the comfort and effectiveness of the uniform.

(p) Bulletproof Vests with Shape Memory Properties: SMAs can be integrated into the design of bulletproof vests to enhance their performance. The material could change its structure in response to the impact of a projectile, redistributing the force and potentially reducing blunt force trauma to the wearer. This adaptive response could improve the overall safety and effectiveness of body armour.

(q) Self-Repairing Textiles: Smart materials, including SMAs, can be used in the development of self-repairing textiles for military uniforms. If the fabric is damaged, SMAs could be designed to revert to their original shape, closing small punctures or tears. This feature increases the longevity of the uniform and reduces the need for frequent replacements.

(r) Enhanced Load Bearing Equipment: Load bearing equipment such as backpacks and harnesses, can be designed with SMA's to adapt to the wearer's movements. The straps and load distribution components could adjust on the soldier's posture and movements, improving comfort and reducing the risk of fatigue or injury.

(s) Adaptive camouflage Cloaks: Integrating SMA's into camouflage cloaks could provide soldiers with an adaptive and chameleon-like capability. The cloak could change its colour and pattern in response to the surrounding environment, enhancing the soldier's ability to blend into different terrains and environments.

(t) Biomechanical Support Systems: SMAs can be used in exoskeletons or biomechanical support systems integrated into military uniforms. These systems could provide additional strength and support to soldiers during physically demanding tasks. The SMAs would adapt to the user movements, enhancing agility and reducing fatigue.

(u) Application in Drones : **Adaptive Camouflage on Drones**: Drones can be equipped with adaptive camouflage systems using SMAs. The outer surface of the drone could change colour or pattern to match the surroundings, providing a stealthy advantage during reconnaissance surveillance missions.

(v) Energy Harvesting for Extended Flight Time: SMAs can be employed in mechanisms for energy harvesting on drones. The mechanical deformation of SMAs during flight, caused by vibrations or movements, can be converted into electrical energy. This harvested energy can supplement the power source and potentially extend the drone's operational time.

Organisations engaged in the R&D and production. DRDO is at the forefront of the research and implication of SMAs including funding several projects. CSIR-NML is working on Ni Mn Ga-based SMAs using melting spinning technology, producing ribbon-geometry, which could be useful for Actuator. IT-M working on various aspects of Ni li- and Ti Ta-based shape memory alloys and the development temperature shape memory alloys for critical applications CSIR-NAL is working on various properties and applications of NiTi alloy. IIT-Kanpur working on a Bio inspired SMA based Actuator. IIT Indore is also working SMA based Actuator, IT-B also working on shape memory alloy particle metallic glass matrix composites Department of Space has authorised NSIL (New Space India Limited) for the technology transfer of met producing NiTi Based SMAs to suitable entrepreneurs/ Industry in India. A Wires India, a Pvt. Ltd. At Ahmedabad, commercially producing Nitinol based SMAs.

SESSION 5 – ADDITIVE MANUFACTURING AND 3D PRINTING

The session was chaired by **Dr Murugaiyan Amirthalingam**, Associate Professor, IIT Madras. He commenced the panel discussion by giving a basic explanation of the concept of 'Additive Manufacturing' to the audience. He said that since Additive Manufacturing (AM) and 3D Printing Technology industry is still in nascent stage, it is the right opportunity to take the lead. He mentioned possibility of adapting additive manufacturing and 3D printing for engineering and biomedical applications, automobiles, etc in addition to defence. He brought out the benefits of metal additive manufacturing in terms of material and energy saving and design freedom and its attributes of being a fully automated operation with limited skilled manpower requirement to realise from digital to physical form without any part-specific tooling requirements. However, he said that the existing "print-ready" alloys cannot cater to the diverse and growing needs of metal AM, especially in the defence sector, and that true benefits of metal AM can only be realized by developing more AM-friendly high-performance alloys.

The first speaker **Sh V Srinivas, Scientist 'E', DMRL, DRDO** spoke about Additive Manufacturing of Metallic Components for Defence Applications. He started by explaining the concept of Metal Additive Manufacturing. He brought out the following advantages of metal additive manufacturing in defence sector:-

(a) Reduced product development lead time.

(b) On-site printing of parts, reduced dependency on supply chain.

(c) Manufacturing of unavailable/ old spares.

(d) Repair and refurbishment of parts.

(e) Manufacturing of critical components with complex geometric profiles.

(f) Manufacture of parts with conformal and internal cooling channels.

(g) Optimized designs for weight reduction and reduced assembly of parts.

(h) Manufacture of multi-material components.

(j) Manufacture of parts with enhanced functional properties and performance.

He gave examples of additive manufacturing being done in the field of aviation and aerospace by GE, Airbus, P&W and NASA. In India, some components for the IAF have been manufactured using AM which have subsequently been certified by Semilac. One such firm manufacturing components is 1 CIMD, Nasik. Once manufactured, defects in AM products are usually at the micro level that causes failure. Hence, inspections of these components need to be at a higher level of characterization. This means that process control is critical and needs to be tightened for reduced rejection of manufactured parts. By means of a few case studies, the speaker showed how, by process control, defects were reduced and achieving increased fracture toughness was possible.

Similarly, the result of the inspection would vary based on from where the sample is extracted from. Usually, two samples from the same manufacture may result in different results. Hence, this necessitates a need for greater study of the process itself. Today, DMRL is working on the design of new super alloys (alloys by design – ABD) using AM and on developing a test methodology for all the processes.

The second speaker **Capt (Dr) Nitin Agarwala,** Senior Fellow, CENJOWS covered the aspects of 3D printing for Ship Repairs. He discussed the possible use of AM for ship repairs. He began by explaining what AM is and then indicated how AM is slowly being studied in the maritime sector. For ships, while the US and the US Coast Guard have installed printers onboard, they have used it to print small parts such as caps, airplane models etc. Discussing a case study of use of AM in ship repairs he showed the cost advantage achieved and that the product manufactured was limited to a non-load bearing member as load bearing members required classification approval process which was still to be defined. He concluded by saying that since AM has merit and is a sure way or encouraging Circular Economy, its acceptance would require more work but is a future technology for use onboard ships.

The third speaker was **Mr Ram Kumar Krishnan**, from Intech Additive Solutions. He covered the subject of Metal Additive Manufacturing through Ultrasonic Atomisation Technology. He discussed the procedure and requirement of developing powders for AM.
He indicated that powder quality, handling, purity and manufacture is a challenge for the industry for which Intech has developed solutions. He indicated that while there are a large number of metals, only 50 of them have been atomized to date and small MOQ (minimum order quantity) is a hold point for atomizing more metals. In this effort of manufacturing metallic AM powders, Intech has collaborated with a Polish firm AMAZEMET and are using ultrasonic atomization which is considered the best process of manufacturing atomized metallic powder for AM.

The forth Speaker **Mr S Murali shankar, Managing Director, Super Auto Forge,** covered the subject of Application of Additive Manufacturing in Industries. He provided an insight on manufacturing cold forged parts which is his company's strength area for the last 50 years. Recently, they have moved to AM wherein they are manufacturing warm forging tools using AM. Such parts can be now manufactured in 78 hours as against 4-6 weeks required in conventional manufacturing process. The printed part has a greater life as internal cooling has been provided to the forged tool. He mentioned that the main challenge in AM is the cost of powder, reducing the build time of parts, increasing productivity and the need for post processing.

The session culminated with a presentation by **Mr Sachin Suramwar**, Gasptops on his company's products like Metal Scan (on-line oil debris sensor providing real-time health monitoring of bearings and gears), Blade Monitor (on-line sensor mounted on engine fan case providing full-time/ real-time detection of blade distortion or cracking) and Chip CHECK (automated chip detector analyser deployable at the flight line/ maintenance bay) for monitoring equipment health. He informed that his company is from the US and provided equipment wherein the mandatory debris analysis of the oil of an aircraft or a ship can be completed within 15 minutes and at the site itself. His product disallows delay in decision making for operational deployment of assets and is simple to use.

Lt Gen Sunil Srivastava, AVSM, VSM (Retd), Director CENJOWS** summarised the key takeaways of the seminar where he highlighted the need to finding indigenous solutions to the services' specific requirements urgently in order to overcome the challenges faced in customising the hardware sourced from abroad in preparing the special matreials for defence usage. We need to have a long term strategy in maintaining the assured supply of special materials during war and peace. He complimented all the session chairs and the panelists for having conducted the sessions in the most professional manner and sharing their knowledge on the various topics and issues that were covered. He also complimented all the participants for the interest and involvement displayed. He also complimented the team of CENJOWS and IMR for successfully organising the event.

Maj Gen Ravi Arora, Chief Editor, Indian Military Review, ended the seminar with a vote of thanks to the Director CENJOWS for having personally selected the speakers and prepared the program for the event, all the sponsors for their efforts and the delegates present for making the event a success.