Additive Manufacturing of Biomaterials: A New Paradigm

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Abstract

Over the last few decades, biomaterials science and biomedical engineering have been perceived as one of the fastest growing areas of research and innovation within the engineering science community, considering the number of scientific discoveries and their societal impact. The upsurge in the clinical demand for reconstructive joint replacements demands new implants with better biocompatibility properties. These attempts were largely directed to re-create functional musculoskeletal systems with considerable potential to treat various types of human diseases, for example, osteoarthritis, osteoporosis, osteomyelitis, so on.

In line with such efforts, this presentation will provide global perspective on the subject with a special emphasis on current efforts to address many of the Indian challenges. As an example to our ongoing multi-institutional center of excellence on biomaterials, I will thereafter present some of our recent results to demonstrate the efficacy of the 3D powder printing to fabricate the Ti6Al4V-based metallic as well as Calcium Phosphate (CaP)-based ceramic scaffolds. While presenting our research results, a major emphasis will be placed on the binder formulation, post-processing treatment, and micro-computed tomography of interconnected porous architecture. The challenges in the fabricating patient-specific implants in 3D powder printing route as well as the myriad of opportunities for future research in this emerging field will be highlighted.

This presentation will conclude with the speaker’s thoughts on translational research programs and with a few examples of interdisciplinary academic programs to enable young researchers to think laterally, while blending sufficient knowledge of biological systems with engineering sciences to develop next generation biomedical materials.

COMPETITIVENESS OF DOMESTIC SPECIAL STEEL PLANTS & THE RELEVANCE OF R&D

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ABSTRACT

There are around twenty-five prominent special steel plants in the country producing annually about 4-5 MMT of steel. These produce many grades of steels routinely to primarily cater to the needs of the automotive, nuclear, oil and gas, tool and die as well as bearing manufacturing sectors. Successful management of special steel plants, due to their small volume production, relies enormously on yield and rejection rate. As in-house R&D is practically absent in all domestic special steel plants, yield losses and rejection rates tend to be generally erratic and often high. Furthermore, ability to adapt to the demanding market scenario as well as to develop new grades of steel, have generally been less encouraging and these grossly affect performance, competitiveness and profitability of many special steel plants in the country. Continuous improvement of plant process performance is a need of the hour and is pivotal to the survival and sustenance of domestic special steel plants.

Over nearly the last two decades, the present author has been engaged with large number special steel plants in the country. Academia–industry collaborations were generally targeted to enhance mill performance and specific objectives included, for example, higher recovery of deoxidiser and alloying additions, effective utilization of low grade feed material, improved ladle stirring and argon consumption, lesser tundish skull, better castability, clean steel and so on. In such endeavor, water modelling, mathematical modeling and plant scale trials/measurements were applied in con-junction to deduce tangible solutions that are easily implementable and fulfill the desired objectives in a cost effective manner. In this presentation, starting with an overview of the domestic special steel sector, its current and future status, a problem of general concern i.e., *cleanliness of steel*, during continuous and ingot casting is discussed elaborately. It is demonstrated that successful process and design parameters can be effectively worked out through systematic R&D studies and help industry deliver cleaner and better products. In such context, it is discussed and re-iterated that R&D is highly relevant to the sustenance of domestic special steel plants and there currently exists enormous scope to this end.

Integrated Computational Materials Engineering (ICME): Past, Present, and Future

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ABSTRACT

Integrated Computational Materials Engineering (ICME)[1] has recently been advocated by the National Academies as a potential to transform manufacturing related to materials processing in the US.[2] ICME entails cradle-to-grave history modeling and multiscale modeling of a material through its manufacturing process and in-service life. A hierarchical multiscale modeling[3] framework will be discussed in the context of using internal state variable (ISV) theory[4] at the macroscale where downscaling constraints start. A discussion of different length scales will be presented related to rate and temperature dependent plasticity and damage evolution in ductile metals along with the modeling of the Process-Structure-Property-Performance (PSPP) sequence. This modeling concept will be shown to address a broad range of engineering problems.

Dr. Horstemeyer's presentation will address the historical developments that led to the notion of ICME. He will also address current applications of ICME from both a science and engineering perspective. Finally, he will make conjectures about the future using ICME concepts.

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Recovering of non-ferrous metals from metallurgical and electronic wastes

Dr. R. P. Das

In India, small and medium scale industries are mostly associated with the processing of metallurgical wastes. Such industries receive little government incentive , except those available to any other SME, and therefore totally revenue driven .These are also low capex, and low entry-barrier industries. However, it is possible to operate a successful recycling industry when the value added products have a knowledge barrier, and when the supply is guaranteed through legal imports. The presentation will highlight these issues, , as well as a few successful cases.

Current Status of Materials and Manufacturing Processes in the Indian Defence Sector

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Abstract

Materials technology is one of the core technologies in defence systems and is a fundamental enabler to improve their performance. Advanced materials enable significant changes in: maneuverability (mobility, speed, agility); force protection (from nuclear, biological, chemical, kinetic, or explosive weapons through stealth, armour and active defence); engagement (highly concentrated and sustained firepower); and logistics (durability, maintainability). Although the usage of polymers, ceramics and composites is gradually increasing in defence systems, metallic alloys are by far the most predominant materials used in today's defence systems and this trend is expected to continue in the near future. Among metallic alloys the ones that have the most applications in defence systems are high strength steels, aluminium alloys, titanium alloys, nickel based superalloys and tungsten based alloys. In this talk the current status of these materials and their manufacturing processes in the Indian Defence Sector as well as the strategy and roadmap going ahead in these areas will be highlighted.

Metallurgical Emissions - Ticking bombs or valuable resources?

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Abstract

With the advancements in metallurgical production processes, especially in iron and steel technology, emissions in the form of slag dumps containing toxic metals and greenhouse gases pose a serious threat to the environment. Governmental regulations are tightened world-wide and the constraints in India are getting stringent. Taking steel as the example, the world production is expected to increase from 1418 M. tons to double the amount. India targets an annual steel production of 300 M. tons by the year 2025, more than three times the production level of today. With the increase in steel production, the emission levels are also expected to rise. Indian national steel policy, on the other hand, aims to decrease the energy consumption, lower the emission of greenhouse gases and, at the same time, increase the productivity. This would imply that the existing steel processes should be extremely well-tuned and newer process routes are to be designed in order to meet the emerging economic as well as environmental challenges. The present talk aims at presenting multi-disciplinary, integrated process solutions that would enable lessening the environmental load from industrial and house-hold emissions.

Currently, India is annually producing 4-7 M.ton steel slag. The chromium content in the slag can vary between 1 – 20 % Cr as oxide. Leaching of chromium from slag dumps by rainwater results in the emission of the carcerogenic Cr^{6+} in the ground water. At the same time, the wastage of resources is exemplified by the Swedish example that the amount of metals in slag wastes per year is higher than the amounts needed annually for steel industry. A book-keeping of strategic metals needed for industrial production in India shows the need to import strategic metals like manganese, vanadium and cobalt. Newer technologies need to be evolved in order to recover metal values from slags and value-added applications of waste products in different areas. The energy wastes can be minimized by optimizing the processes and also by recovering the inherent heat from the tapped slag.

The solution to the environmental challenges faced by the metallurgists lies in finding integrated solutions from adjacent areas widening the perspectives beyond conventional metals production technology. The big Fe-C-Ca cycle analysis, wherein the reactions involved in iron and steelmaking are integrated with coal gasification and cement making, closing the bigger loop is an attractive possibility. India has an unused heap of coal ash amounting to 100 M tons only in the year 2013. India is the third largest garbage generator in the world. Our total daily production of sewage amounts to 30 000 M. litres of which we process only $1/4^{th}$. The combustion of sewage sludge combined with coal gangue is not only a source of energy; but also takes care of the large volume of sludge produced. The ashes can be suitably tailored to be slag formers. Coal

ash combined with ash from sewage sludge provides an excellent raw material for the production of clinkers and other value-added products. These are some examples of multidisciplinary integrated solutions. In this respect, care should be taken that harmful trace elements do not end up in the biological cycle.

The value addition by an integrated process solution is very significant in the case of the treatment of aluminium dross containing AlN which emits environmentally undesirable ammonia gas in contact with water. Indian secondary aluminium industries produce nearly 3.5-4.5 Lakh ton of dross. Utilization of ammonia evolved in water-leaching of the dross by absorbing the same in carbonated water results in the production of ammonium bicarbonate which is a useful fertilizer with the added advantage of fixing the carbon. The leach residue has been shown to be a very useful raw material for the synthesis of SiAlON ceramics.

It is emphasized in the present lecture that process metallurgists need to expand their horizons and find inter-disciplinary solutions to meet the environmental challenges of today and tomorrow.

Key words: emissions, slags, dross, toxic contaminants, integrated solutions.

Mechanical behaviour and testing at small length scales: from plasticity in silicon to brittleness in copper

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The strength of engineering systems in the range of ~ 1 micron to 1mm offers particular challenges in testing and in understanding materials behaviour. Such systems may arise in electronic devices in the form of thin films or MEMS, as protective coatings on high temperature materials or on graded microstructures generated in service through tribological or radiation damage. In recent times, a number of testing methods have been introduced that combine one or more of micromechanical handling, in-situ observation and full field deformation measurements. Such techniques have allowed the detection of behaviour as diverse as plastic flow in small samples of silicon, brittle behaviour in copper, steep R-curves in a high pressure form of silica that undergoes transformation toughening and so on. After a brief review, this talk will focus on 3 examples of work on metallurgical systems in our laboratory. In the first, we describe the use of a new geometry to measure the effect of platinum on the toughness of 100 micron thick graded beta NiAl bond coats on superalloys. This test technique is then adapted to examine fatigue crack growth where small changes in stiffness are the prelude to a sudden jump in crack length. In the final example of small scale testing, it is shown how small cantilevers of aluminium can be crept under bending to allow the determination of the usual creep parameters. Not only does this method allow the minimal use of material for life prediction studies, but interesting length-scale effects appear as the beam thickness drops below ~ 0.5 mm.