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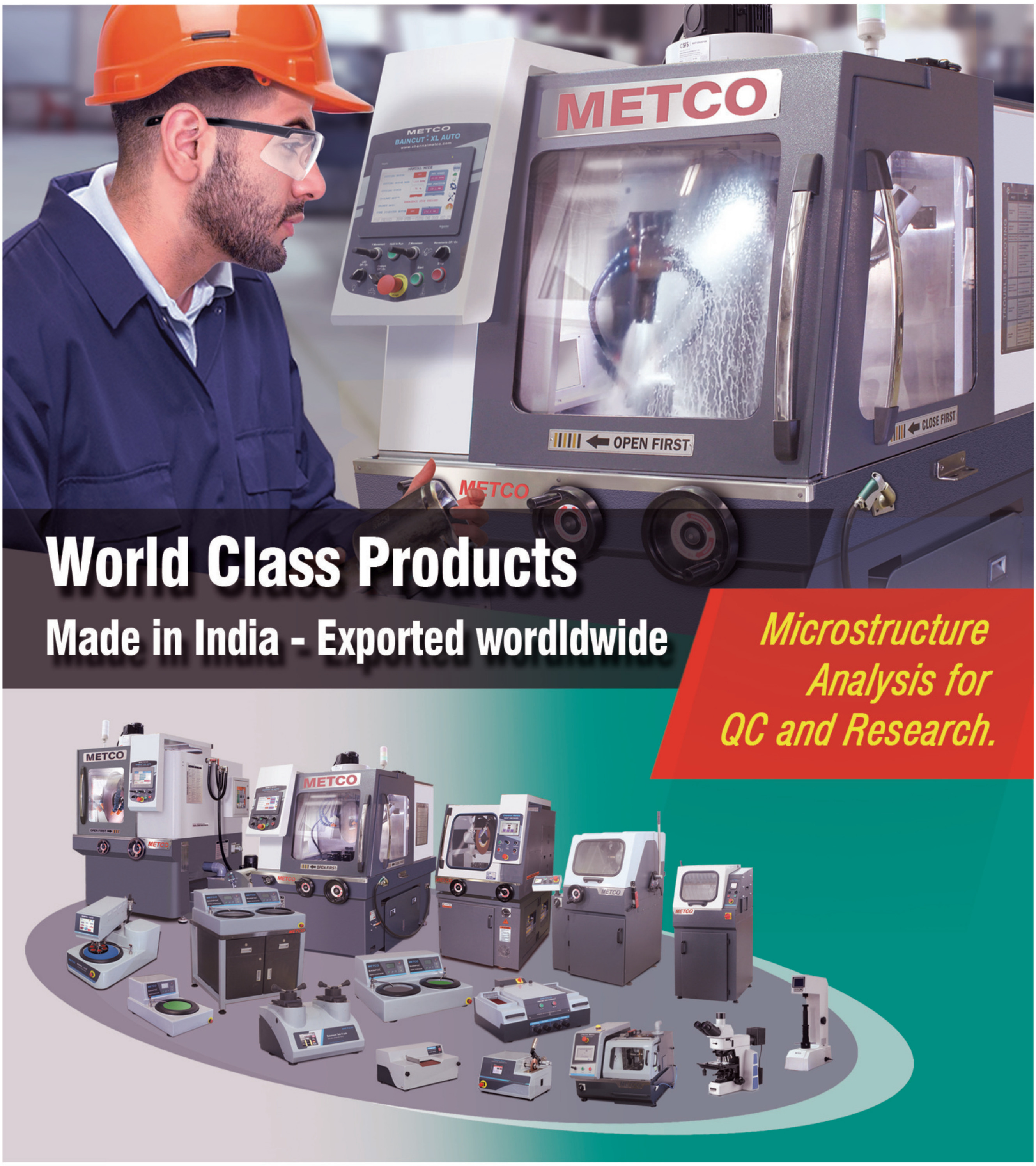
GOLD MEDAL LECTURE

Research and Development in Materials for Indian Space Program (2nd Part)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E-mail: secretarygeneral.iim@gmail.com, iimmetalnews@yahoo.com
Phone: 033-2367 9768 / 2367 5004
Website: www.iim-india.net
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THE INDIAN INSTITUTE OF METALS

GD Birla Gold Medal Lecture

Research and Development in Materials for Indian Space Programs (2nd part)

S V S Narayana Murty
General Manager, Material Development and Production Group,
Materials and Manufacturing Entity, Liquid Propulsion Systems Centre,
Trivandrum - 695 547

Abstract

Aerospace systems are characterized by controlled mass, limited volume and high reliability. Limits on materials often pose technical obstacles to designers as also in improving the safety and reliability of aerospace systems. This further gets compounded by the fact that these materials should not only survive but also perform under extreme operating conditions.

In this second part of the article (the 1st part appeared in December, 2022 issue of Metal News), the scientific and technological efforts made for several advanced and new aerospace materials leading to their semi-bulk production are explained. This is followed by a few case studies on testing and characterization for qualifying flight hardware and new processes for the Indian Space Programme.

1. Introduction

Deformation processing is an important step in the manufacture of engineering components and is used not only to achieve the required shape but also to impart desirable changes in the microstructure and properties. In designing working processes for components made of complex engineering materials, the most important task is the selection of the controlling process parameters that will ensure part quality as well as specific mechanical and physical characteristics. The controlling process parameters are the sequence and number of material flow operations, the heat-treating conditions, and the associated quality assurance tests. In order to achieve defect-free wrought products in complex engineering alloys or optimise the existing processes to improve the yield, evaluation of workability of materials is essential and some important results obtained by author's research studies [Refs. 5-60 of the 1st part of this 2-part article] are described in this article.

2. Deformation processing: Development of a simple instability criterion

Workability problems may arise when metal deformation is localized to a narrow zone. This results in a region of different structures and properties that can be the site of failure in service. Localization of deformation can also be so severe that it leads to failure in the deformation process. Flow localization may occur during hot working in the absence of frictional or chilling effects. In this case, localization results from flow softening (negative strain hardening); flow softening arises during hot working as a result of the structural instabilities such as adiabatic heating, generation of a softer texture during deformation, grain coarsening or spheroidization. A fundamental understanding of the workability of a material is essential for developing scientific techniques in mechanical processing.

The major emphasis in workability is on measurement and prediction of limit of deformation before fracture. Flow stress data are essential in the development of basic equations and processing maps. One of the requirements for process modelling is a knowledge of the material flow behaviour for defining the deformation maps that delineate 'safe' and 'non-safe' hot working conditions. These maps show in the processing space (that is on axes of temperature, T and strain rate, ~) the processing conditions for stable and unstable deformation. The range of temperatures and strain rates for stable material flow, useful in the development of process control algorithms should be obtained from physical quantities, which can be evaluated from the test data. As such there is no unique instability theory to define the regions of unstable flow during hot deformation which is applicable for all the materials.

2.1. RR Rings of Ti-6Al-4V

An illustrative example on the generation of defects and formation of inhomogeneous microstructure during the hot deformation is presented here. The material is Ti-6Al-4V and the product is a ring rolled ring of size OD:1435 x ID: 1245 x HT: 243 mm that was processed from hot worked billets. These rings revealed ultrasonic indicators/observations after the final heat treatment and machining. Surface defects and radiography indications on the finished rings at ~2 mm thickness were noticed during final fabrication. These type of defects (Fig. 1) at prior beta grain boundaries and local microstructural heterogeneities arise from the billet-stage microstructure and the process parameters adopted for hot working [1, 2].

Process modeling of a hot working operation is thus a powerful tool that requires knowledge of the material flow behavior for defining deformation maps that define 'safe' and 'non safe' hot working conditions. These maps show in the processing space, that is on the axes of temperature and strain rate, the processing conditions for stable and unstable deformation. The mechanical behavior of materials under processing is generally characterized by the constitutive equations which relate the flow stress (σ), strain (ε), strain rate ($\dot{\varepsilon}$), and temperature (T).

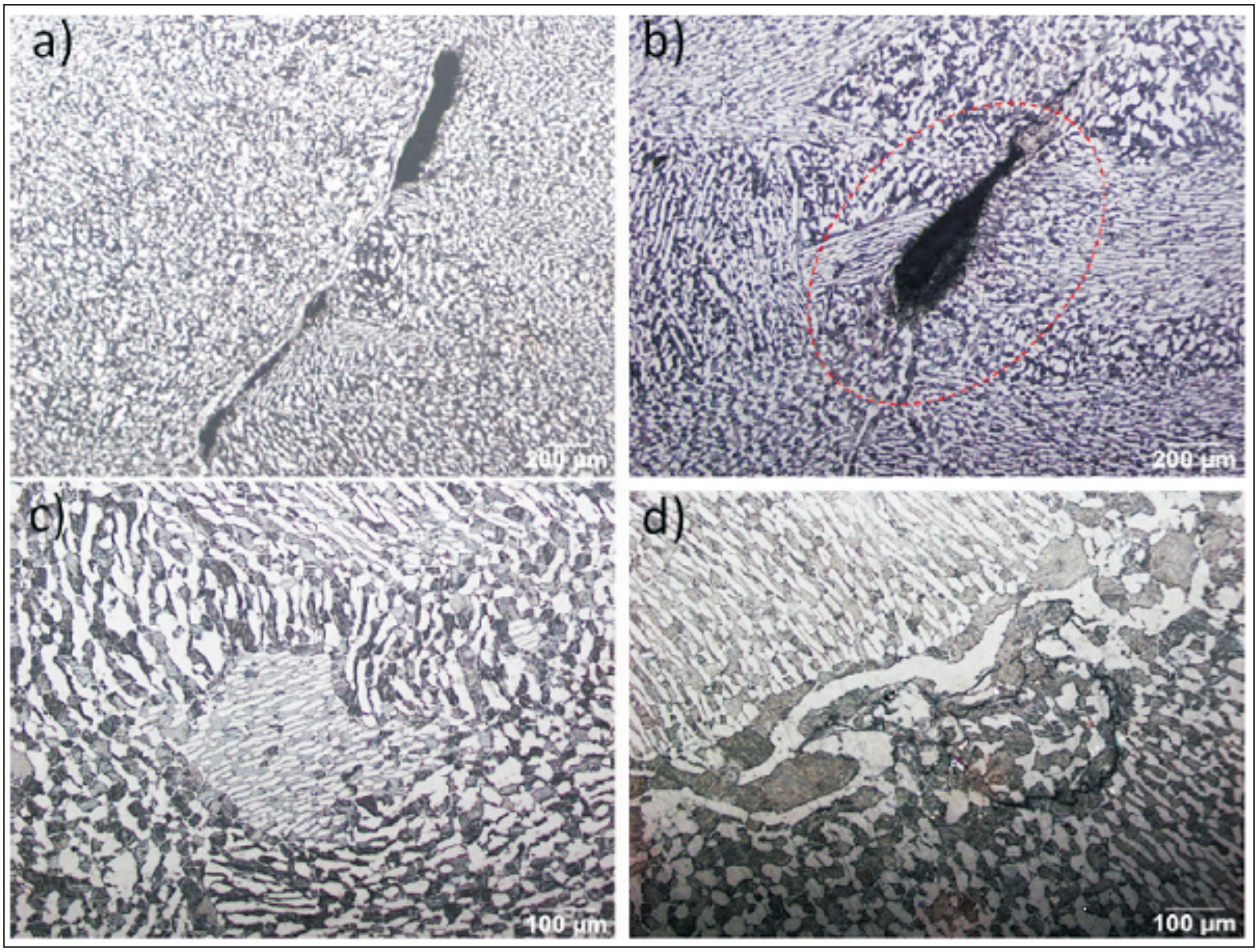

Fig. 1 : (a and b) Defects generated in Ti-6Al-4V ring rolled rings at prior beta boundaries taken at two different magnifications; (c and d) show optical photomicrographs of microstructural heterogeneities [1, 2].

2.2. AA AFNOR 7020

A simple metallurgical instability condition in terms of efficiency of power dissipation (η) and strain rate sensitivity (m) was proposed as $2m < \eta$ to define the regions of stable and unstable flow during hot deformation of materials which is valid for any type of σ - $\dot{\varepsilon}$ curve. Thus for stable material flow, $\eta < 2m$ and $0 < m < 1$. The applicability of this metallurgical instability criterion has been verified on several materials. An example of a processing map for AFN0R7020 Aluminum alloy showing the regions of 'stable' and 'unstable' regions along with microstructural observations is shown in Fig. 2 [3].

3. Development and characterization of Aerospace Materials

3.1. 3rd Generation Al-Cu-Li alloys

Presence of lithium in Al-Cu-Li alloys makes it difficult to process the material through conventional direct chill (DC) casting route adopted for other aerospace aluminum alloys. No facility exists in India for processing Al-Cu-Li alloys which needs molten lithium to be added to molten aluminum. The reactive nature of lithium makes it mandatory to handle the metal under controlled atmosphere and its low density demands development of techniques by which homogeneity of the melt is assured. In this direction, development of Aluminum-Copper-Lithium alloy AA2195 (Al- 4Cu-1Li-0.35Mg-0.35Ag-0.12Zr) is attempted. This alloy has been successfully used in the external tank of the space shuttle. In order to process the material under controlled atmosphere, the available in-house vacuum induction melting facility was used for processing the alloy. A large number of melting trials were conducted in the first phase and ingots weighing 5-6 kg were processed meeting the targeted chemical composition [4]. The cast ingots were homogenized, forged and rolled and imparted the desired tempers to evaluate the mechanical properties [5]. Subsequently, the technology was scaled up to 200 kg and 1000 kg. to produce Al-Cu-Li alloy ingots of AA2195 [5]. Thermo-mechanical processing was carried out to realize plates, sheets and rings and the mechanical properties of these materials were evaluated at RT, 77 K and 20 K. Detailed microstructural analysis was carried out to understand the evolution of microstructures and precipitates. With these developments, technology for indigenous processing of third generation Al-Cu-Li alloys was established.

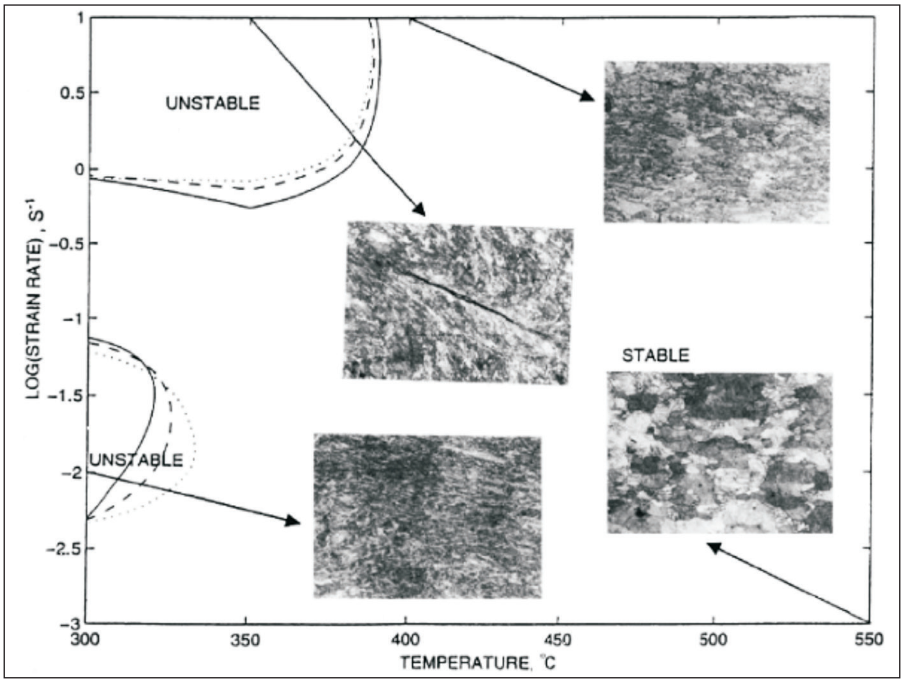

Fig. 2 : Processing map for AFNOR 7020 Aluminum alloy based on the instability condition (10) for superimposed strains — 0. 1; 0. 3; and 0. 5, along with microstructural observations of deformed compression specimens [3].

3.1.1 Mechanical properties and microstructures of Indigenous AA2195-T87 temper sheets:

Tensile testing was performed on a 4 mm thick sheet of the aluminum-lithium alloy AA2195 in T87 (solution treatment + water quenching + 7% cold work + peak aging) temper; the sheet was subjected to 7% cold working by combination of cold rolling and stretching, over a temperature range from ambient to liquid hydrogen (20 K) conditions. Mechanical properties were evaluated in longitudinal as well as transverse directions to characterize anisotropy with respect to strength and ductility and are presented in Fig. 3. Strength and ductility were compared to the conventional aluminum alloy AA2219-T87, developed for similar cryogenic applications [6]. Decrease in test temperature led to higher strengths with little or no change in ductility. As the temperature decreases, the difference between ultimate tensile strength as well as yield strength for two different combinations of cold roll and stretch studied in the present work, narrows down and becomes equal at 20 K. Fig. 9 presents comparison of mechanical properties of AA2195 in T8 temper at RT, 77 K and 20 K, both in longitudinal direction and (b) transverse direction. Fig.10 presents the details of the transmission electron microscopic studies conducted for the indigenously processed AA2195 [3].

3.1.2 Hot deformation behavior of Sc/Nb modified AA2195 Al—Li—Cu alloys:

The thrust to increase payload and fuel efficiency has forced Al-alloys manufacturers to develop new alloys and improve performance of existing ones by tailoring their microstructure, heat- treatment and composition. Scandium is one of the most promising microalloying elements to Al-alloys as it offers many advantages such as it (i) refines as-cast billet grain size, with formation of equiaxed grains (ii) provides solid solution strengthening and dispersion hardening from nano-meter sized coherent Al_3Sc dispersoids (iii) improves the strength by 20-50% in Al-Sc alloys over Sc-free Al alloys (iv) is the most effective recrystallization inhibitors in Al-alloys by raising the recrystallization onset temperature (v) assists in the nucleation of strengthening precipitates and improves their coarsening resistance during high temperature exposure (vi) improves hot-cracking resistance during welding with enhanced post weld strength (vii) reduces the Brass texture component fraction, which in turn, decreases anisotropy in mechanical properties and improves formability. Despite all these benefits of adding Sc in Al-alloys, its widespread industrial use has been limited due to high cost of Sc, scarcity of Sc-deposits and lack of reliable source of supply.

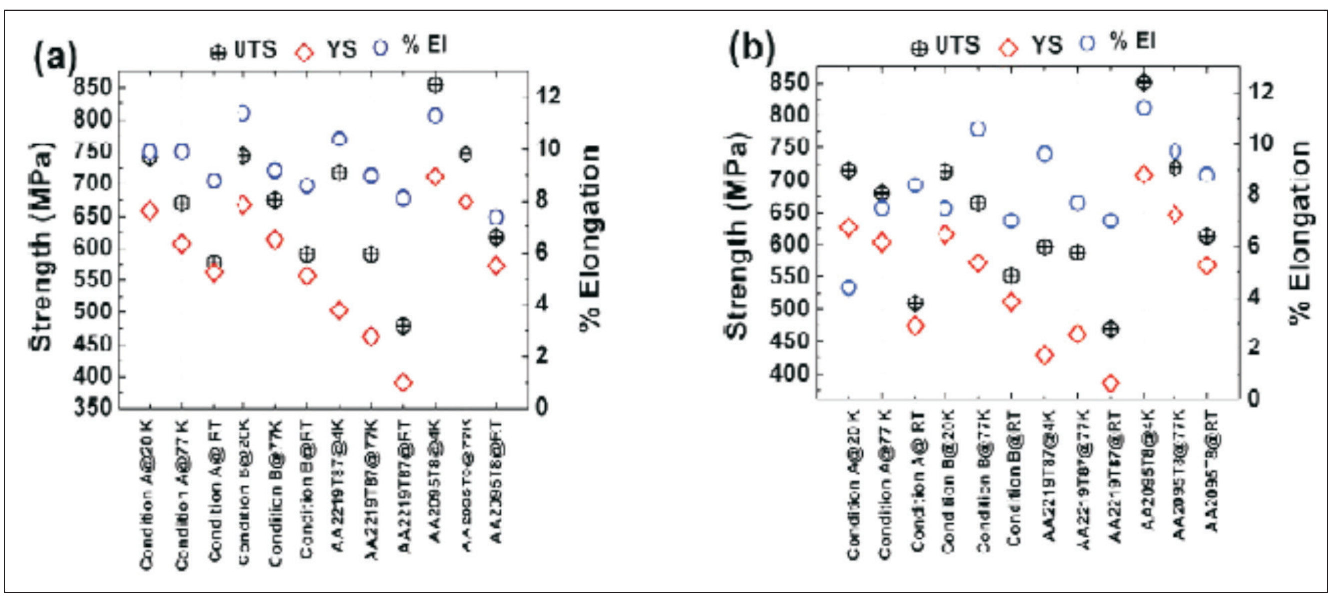

Fig. 3: Comparison of mechanical properties of AA2195 in T8 temper at RT, 77 K and 20 K in (a) longitudinal direction and (b) transverse direction [6].

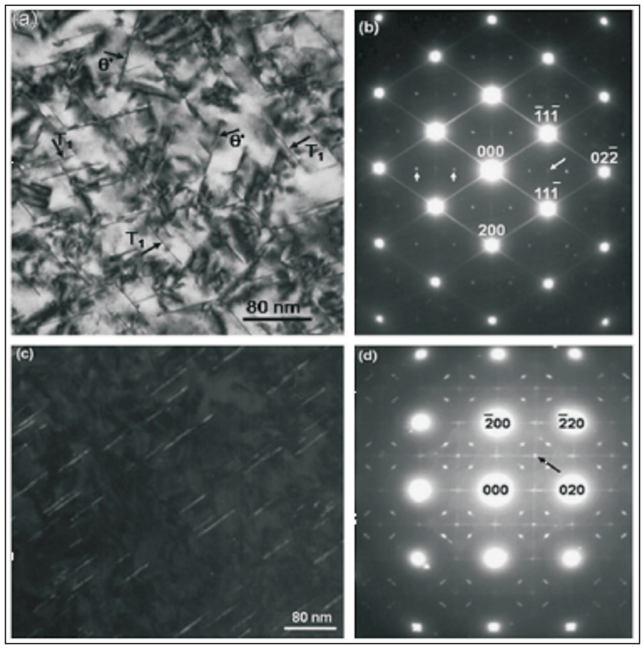

Fig. 4: (a) BF transmission electron micrograph in the (011) Al projection. Few T1 and θ' plates are marked by arrows. (b) SAEDP in (011) Al projection corresponding to (a) showing streaks along (111) Al directions (c) CDF image using one set of streaks along (111) Al direction in (b) showing thin T1 plates. (d) SAEDP in the (001) Al projection showing streaks along (200) Al directions through the matrix Al reflections and through the {011} θ' spots (one marked by a narrow) due to θ' plates forming on {100} Al planes [7].

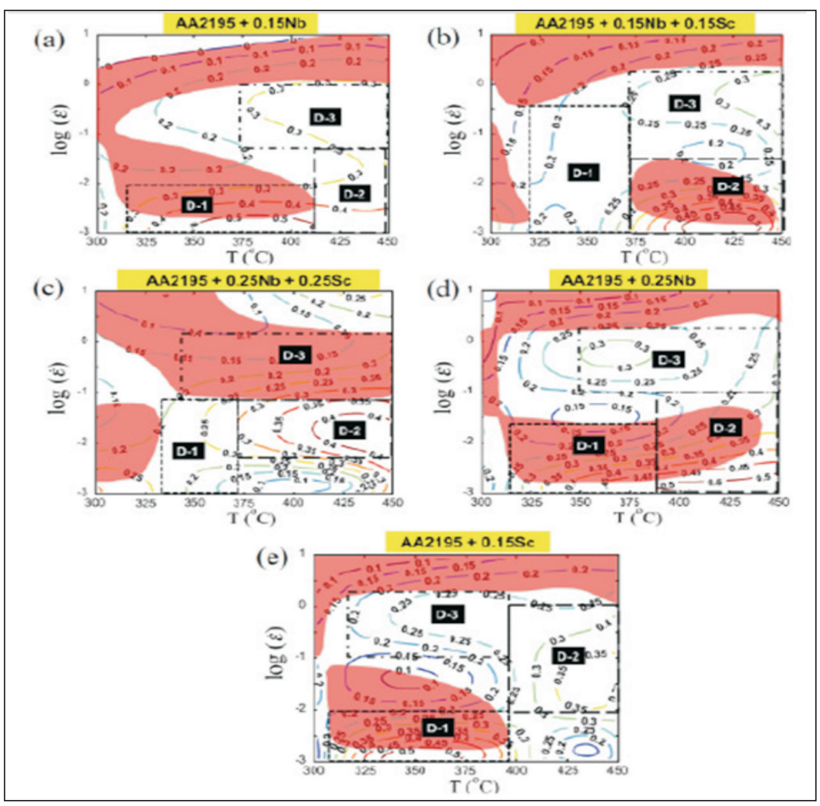

Fig. 5: Processing maps of the Sc/Nb modified AA2195 alloys generated at a true strain of ε = 0.5. The shaded regions in red indicate possible flow instability formation [8].

The hot workability of third generation AA2195 alloy with different Sc (0.15 - 0.25 wt.%) and Nb (0.15-0.25 wt.%) additions in the homogenized condition was investigated using processing maps approach [8]. The Sc and Nb additions were found to help in refining the as-cast grain size of AA2195 and changing the morphology from less dendritic grain structure to a globular or equiaxed form. Hot compression tests carried out in the temperature, *T*, range of 300-450 °C and strain rate, $\dot{\varepsilon}$, of 10^{-3}-10 s^{-1} were utilized to generate processing maps at a true strain, ε = 0.5. The flow curves of the alloys exhibit a typical dynamic recovery (DRV) characteristics and Arrhenius-type constitutive equations successfully predicted flow stress of the alloys. The results obtained from the processing maps and complementary microstructural analysis of the deformed specimens revealed that 0.15 wt.% additions of Sc and Nb (separately or in combination) are ideal to improve its workability. However, increasing Sc and Nb contents to 0.25 wt.% relatively expanded flow instability regions as shown in Fig. 5.

3.2. Copper alloys for thrust chambers

In view of their high thermal conductivity, copper alloys are the preferred choice for applications involving high heat flux, such as thrust chambers of rockets. Cu-Cr-Zr-Ti alloy is used for the fabrication of inner liner of regeneratively-cooled thrust-chambers in Indian launch vehicles and are critical to the successful performance of the cryogenic/semi-cryogenic engines [9, 10]. These thrust chambers are fabricated by vacuum brazing of copper and steels shells and the inner copper liner is multi-stage deep drawn from copper plates. As these copper plates are hot rolled stock, the effect of initial grain size on the hot workability becomes important.

3.2.1 Effect of grain size on hot deformation behavior of Cu-Cr-Ti-Zr alloy:

The effect of initial grain size on the hot deformation behavior was studied in detail [11]. At higher deformation temperatures, fine grained specimens exhibited early onset of dynamic recrystallization (DRX) compared to coarse-grained specimens. Microstructure examination revealed a decrease in the extent of DRX and an increase in deformation twinning with increase in initial grain size. The failure in coarse-grained specimens was in the form of wedge cracking observed at triple junctions at lower deformation temperatures. The higher stress values exhibited by coarse grained specimens compared to fine grained specimens was attributed to the absence of DRX and the strain being accommodated by deformation twinning rather than grain boundary sliding (GBS) due to limited grain boundary area. Processing maps using the dynamic material model (DMM) were plotted for three initial grain sizes and were validated with optical microstructures.

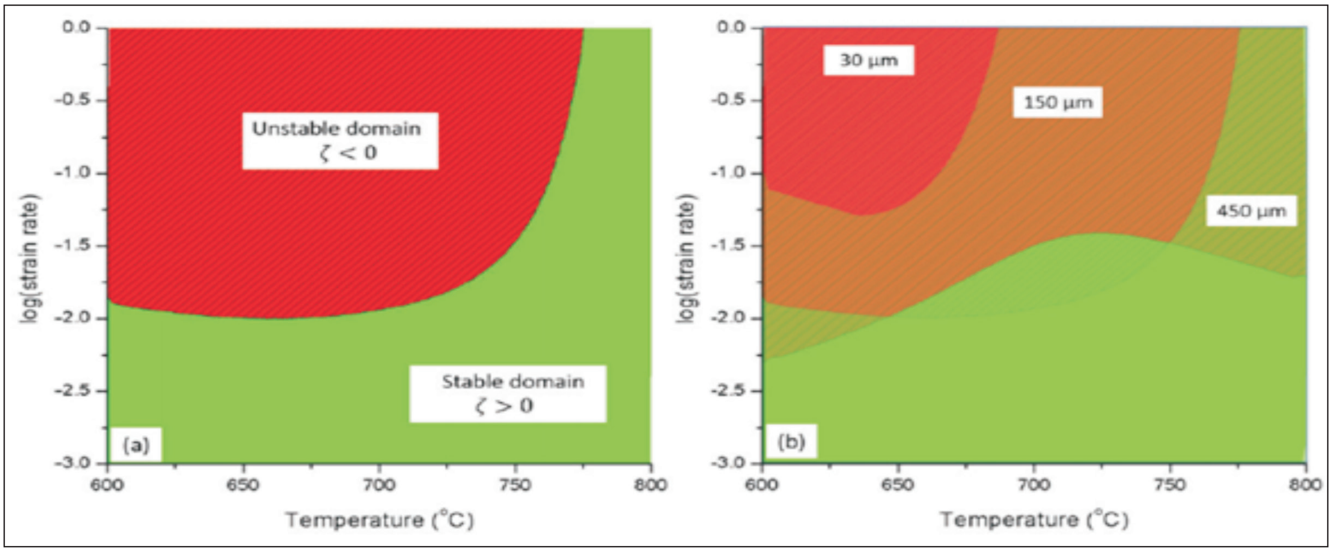

Fig. 6: (a) Contour map showing the safe and unsafe hot working domains based on the instability parameter (ζ) plotted for the alloy with initial grain size of 150 µm and (b) contour maps for all three initial grain sizes (30, 150 and 450 µm) superimposed upon each other [11].

The 'unstable/unsafe' deformation domain was found to be wider with increase in initial grain size as shown in Fig. 6. This study confirms increased difficulty in hot working and reduced microstructure control with increase in initial grain size. The effect of deformation mode and DRX under large plane strain conditions was studied [12, 13].

3.2.2 Development of Cu-8Cr-4Nb alloy through powder metallurgical processing:

Cu-8Cr-4Nb (at%) alloy is commonly processed by inert gas atomization followed by consolidation using hot extrusion technique. Since the Cu-Cr-Nb alloy is made from powder metallurgical (P/M) technique, which is known for producing near net shape components, the knowledge of its mechanical properties in the as Vacuum Hot Pressed followed by Hot Isostatic Pressed conditions is essential. As the alloy is particularly developed for high temperature applications, the evaluation of high temperature mechanical properties is also an important aspect. Fig. 7 (a-d) shows some of the products that were processed from Cu-8Cr-4Nb powders and Fig. 7 (e) shows the stress-strain curves for hot-rolled samples, tensile tested at different temperatures [14]. It can be observed that the tensile strength of Cu-Cr-Nb alloy samples decreases with increase in temperature: this is observed for both the hot-pressed and hot-rolled material. Moreover, the tensile strength of the hot-rolled samples is comparable to that of the hot-pressed samples at all temperatures. However, the strain to failure for the hot-pressed material is in a close range of 0.15 to 0.23, whereas, it is much higher in case of the hot-rolled samples and even it has reached to 0.57 at 700 °C. The enhanced ductility of the hot-rolled Cu-Cr-Nb sample at 700 °C is shown by all the tested samples. Interestingly, both the hot-pressed and hot-rolled materials have shown a drop in ductility at a temperature of 500 °C compared to room temperature (RT). Copper and its alloys are reported to show a drop in ductility at temperatures between 300 °C to 600 °C. The above phenomenon is called as 'Intermediate Temperature Embrittlement (ITE)' or 'Ductility Trough Behaviour' and is associated with nucleation, growth and coalescence of voids at grain boundaries resulting in brittle intergranular fracture. Even though the effect of intermediate temperature embrittlement is suppressed by second phase particles i.e., Cr_2Nb in Cu-Cr-Nb alloy, the presence of porosities in the hot-pressed alloy leads to lower ductility at higher temperatures. The enhancement in ductility for the hot rolled material is attributed to the fragmentation of prior particle boundary network and reduction in pore size and porosity during hot rolling.

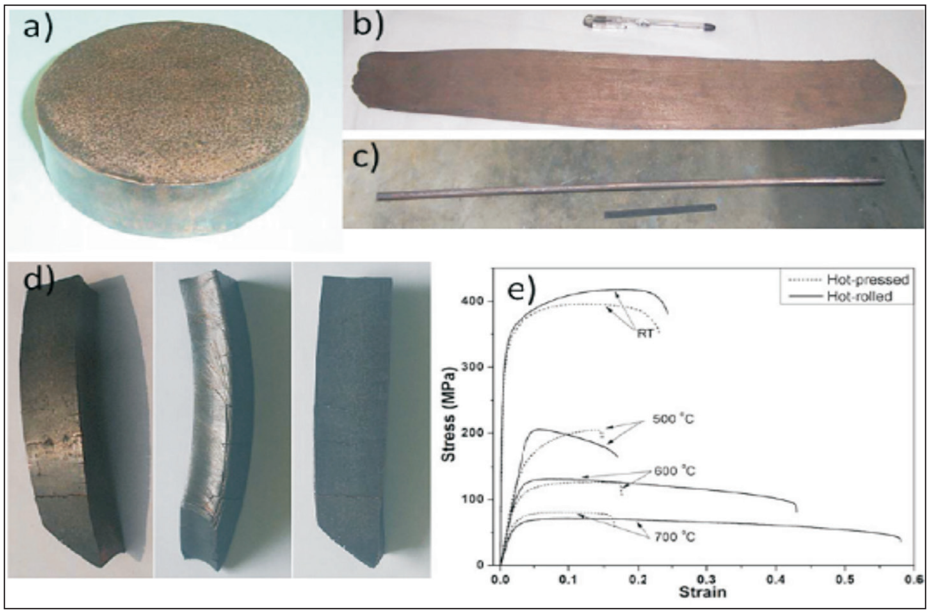

Fig. 7: (a) Cu-8Cr-4Nb alloy hot pressed disc; (b) hot rolled sheet from the disc; (c) rod rolled from disc; (d) defects noticed during deformation; (e) stress-strain curves for Cu-8Cr- 4Nb in hot pressed and hot rolled conditions [14].

3.3. Development of Boron- added Titanium alloys

Ti-6Al-4V is one of the most versatile of Ti-alloys which occupies a prime position among the Ti-alloys for use in strategic sectors. Ti-5Al-5V-2Mo-1Cr-1Fe is a high strength martensitic (α+β)-titanium alloy which possesses comparable strength and superior hardenability to that of the workhorse Ti-6Al-4V. This alloy is being used as a liner material for composite-overwrapped pressure vessels for high-pressure helium-gas storage applications in launch vehicles and satellites. As substantial payload advantage can be obtained by utilizing higher strength titanium alloys, detailed investigations were conducted on a near-P Ti alloy with a composition Ti-5Al-5V-5Mo-1Cr-1Fe (Ti-55511) processed by double Vacuum Arc Remelting (VAR) route. The effect of boron addition (up to 0.12 wt.%) on the as-cast microstructure and β-transus (T_β) of the alloy was studied and characterized in detail [15]. Boron addition resulted in refinement of the as-cast microstructure due to precipitation of titanium boride (TiB) whiskers along the grain boundaries. The grain size in the as-cast Ti-5Al-5V-5Mo-1Cr-1Fe alloy having 1200-2400 µm was refined down to 300-600 µm by addition of ~0.12 wt.% boron. Ti-55211 is a popular (α+β)-Ti alloy which exhibits good hardenability and high strength due to the formation of a' martensite. The effect of Boron content on microstructure evolution in near-β Ti-55511 titanium alloy in both as-cast and wrought conditions has also been studied. It was confirmed that TiB_2 was more stable phase in the as-cast alloy when heat- treated above 973 K using the above techniques. It was found that boron was ineffective in retarding the grain growth at temperatures above T_β.

3.3.1 Deformation behavior of bare and Boron-modified Ti-alloys:

The hot deformation behavior of Ti-55211 and Ti-55511 alloys at elevated temperature and the corresponding microstructure evolution is studied so as to safely form/forge them into the necessary shape/size without any defects. The Ti-55211 alloy in both as-forged and heat treated conditions exhibited typical superplastic characteristics with large elongations to failure (~200-230%) associated with high strain rate sensitivity (m) values (0.2-0.4) at the test temperatures near its T_β. On the other hand in Ti-55511 alloy, the total elongation to failure reduced to ~90-190% at test temperature >1123 K with 'm' values of ~0.3-0.5 in as-forged condition and m~0.20-0.35 in β (1173 K) heat-treated condition (Fig.14). However, the tendency for excessive grain growth under high temperatures limits its potential applications due to drastic reduction in strength with temperature and poses difficulties during forming. The near-β, Ti-55511 alloy was modified with 0.06 and 0.12 wt.% B to investigate its effect on the microstructure and high temperature tensile behavior. The boron addition led to significant grain refinement and changes in morphology of a-phase from lamellar to globular. High temperature tensile behaviour showed that the alloy with 0.06 wt.% B displays superplastic characteristics with maximum elongation to failure of 385% at 1123 K and an initial strain rate of 1×10^{-3} s^{-1}. Cyclic strain rate tests indicated that the 0.06 wt.% B alloy exhibits high strain rate sensitivity (m) values in the range of 0.3-0.8, which suggests that grain boundary sliding (GBS) to be the dominant strain-contributing mechanism for the observed super-plasticity at elevated temperatures.

Processing maps were developed for Ti-55211 and Ti-55511 alloys with and without boron through hot isothermal compression testing over a wide range of strain rates (1×10^{-2} s^{-1} to 10 s^{-1}) and temperatures (1093 K to 1223 K). The effect of molybdenum on compressive flow behavior of Ti-5Al-5V-(2-5) Mo-1Cr-1Fe alloy has been studied by comparing the flow curves of alloys with 2% Mo and 5% Mo. Similarly, the effect of boron has been investigated by comparison of flow curves of Ti-55511 alloys with and without boron. The microstructures of the deformed samples were also observed to understand the deformation mechanisms operating under test conditions.

3.3.2 Effect of B on hot tensile deformation behavior of Ti-5Al-5V-5Mo-1Cr-1Fe alloy:

Fig. 9 illustrates the typical super-plasticity characteristic curves in terms of the variation in flow stress for a fixed strain value, ε=0.2 ($\sigma_{0.2}$) as a function of strain rate at different test temperatures for Ti-55511-0.06B alloy (Fig. 9a), and the variation

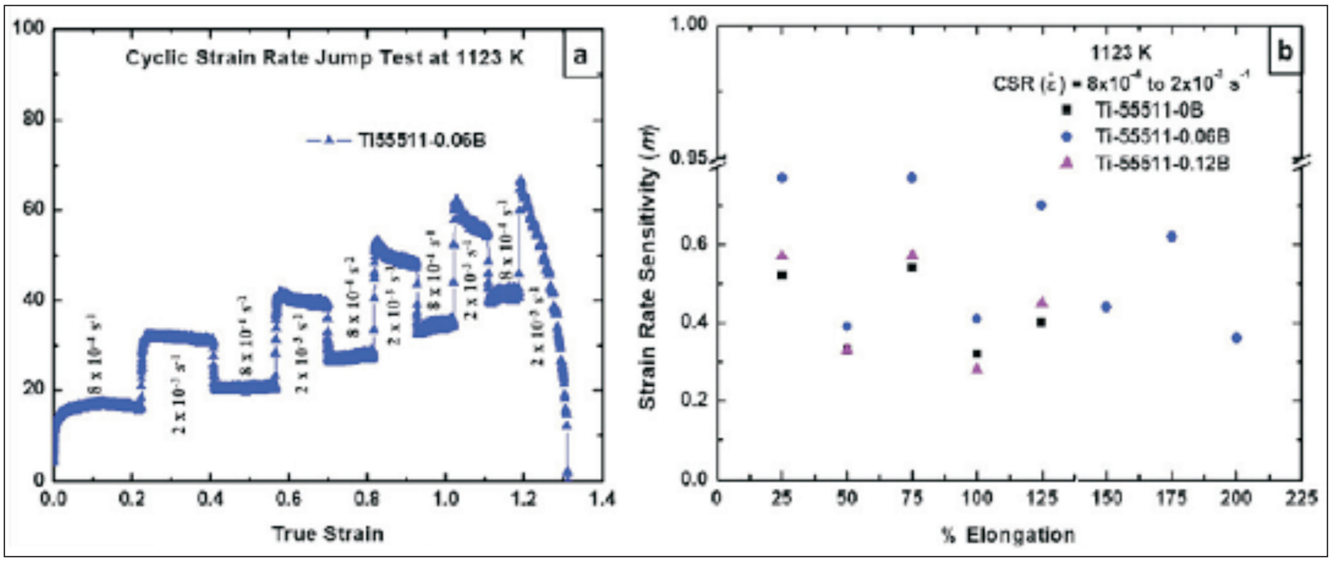

Fig. 8: Flow curve of Ti-55511-0.06B alloy obtained by cyclic strain rate test performed between 8×10^{-4} s^{-1} and 2×10^{-3} s^{-1} at 1123 K and (b) the variation in strain rate sensitivity (m) values for three different Ti-55511 alloys as a function of strain at 1123 K [16].

in $\sigma_{0.2}$ (Fig. 9b) and total elongation to failure (Fig. 9c) against strain rate at 1123 K for all the three alloys. The alloy containing 0.06% B exhibited decrease in flow stress with decreasing the strain rate as well as increasing the test temperature up to T_β. At lower strain rate of 1×10^{4} s^{-1}, the alloy showed anomaly in flow stress with temperature (above T_β). This can be due to differences in diffusion characteristics with phase change. Under optimum test temperature (1123 K), the alloys exhibited typical sigmoidal curves for flow-stress variation and bell curves for elongation and displayed 1×10^{3} s^{-1} as the optimum strain rate. This study indicates that the Ti-55511 alloy containing 0.06% B shows good uniform elongation to failure at relatively lower test temperatures (1073-1123 K) and higher strain rates (~1×10^{3} s^{-1}) compared to the other near-β Ti alloys.

4. Mechanical properties of materials at low temperatures

Liquid hydrogen (Boiling Point 20 K) is the fuel and liquid oxygen (Boiling Point 90K) is the oxidizer in cryogenic propulsion systems; therefore propellant tanks and materials used in the engines are exposed to these extreme temperatures [18]. Therefore, it is essential to understand the behavior of parent materials and weld joints of these systems at the operating temperatures. ISRO

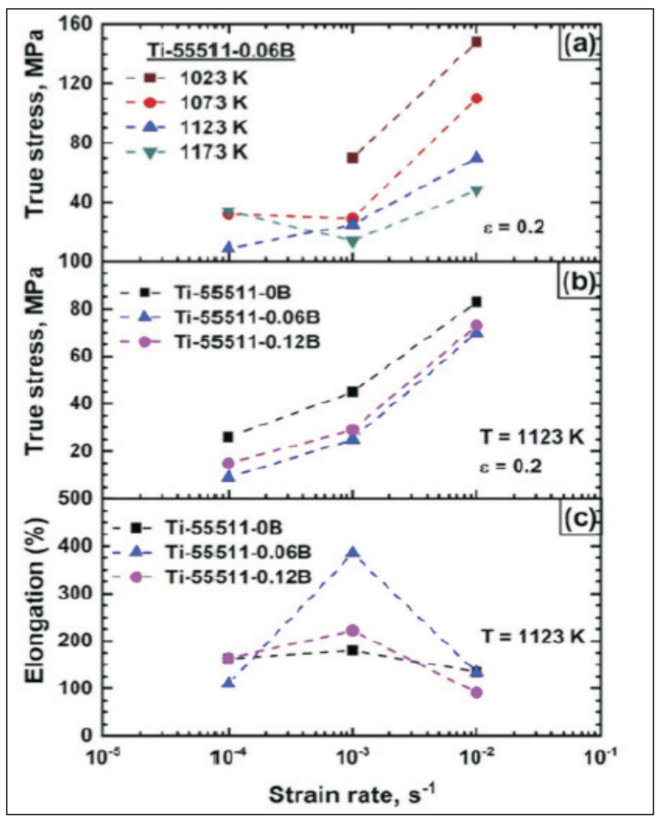

Fig. 9: Plots of superplasticity characteristic curves showing (a) true stress at ε=0.2 vs strain rate at different test temperatures for Ti-55511-0.06B alloy, and (b) true stress at ε=0.2 vs strain rate and (c) total elongation to failure vs strain rate for three alloys at test temperature of 1123 K [17].

propulsion complex located at Mahendragiri is the only facility in the country having capability to test mechanical properties of materials down to 4 K and is used extensively for research and development of materials and processes as well as for their qualification. Further, there are occasions where studies need to be conducted on specific issues related to flight hardware or for qualifying the process changes. Two such important studies are discussed below.

4.1. Effect of long-term natural aging on the tensile and fracture properties of aluminum alloy AA 2219-T87 parent and welds at room and cryogenic temperatures

AA2219-T87 is the material of choice for the fabrication of propellant tanks for both earth atmospheric as well as cryogenic stages. These propellant tanks are fabricated by auto tungsten inert gas (TIG) welding of AA2219-T87 sheets with AA2219-T851 rolled rings using AA2319 filler wire. AA2219 is selected for its good combination of strength to weight ratio, ductility, weldability, resistance to stress corrosion cracking and excellent mechanical/fracture properties at cryogenic temperatures. After fabrication, these tanks are rigorously tested using non-destructive testing techniques, qualified for flight through proof-pressure testing. They are protected against corrosion and stored under controlled conditions for use as and when required. Sometimes, due to certain schedule related issues, these tanks are used after a long time and hence need assurance that the product is flight-worthy. Characterization of the long-term behavior of materials exposed to ambient conditions is an important concern for aluminum alloys as they constitute the majority of critical aerospace structures. There is no literature on the effect of long-term storage on mechanical properties and fracture toughness of AA2219. The problem is more complicated in weld joints as the microstructure of the joint is in as-cast condition and the fabricated tanks are not post-weld heat-treated. Further, these tanks store liquid hydrogen (20 K) and liquid oxygen (77 K). Therefore, the behavior of both parent and weld joints of long term natural aged materials at room and cryogenic temperatures needs to be evaluated and studied for any change in microstructure and mechanical properties. Therefore, a study was done to understand the effect of long term (11 years) storage at ambient conditions on the tensile properties and fracture toughness of AA2219 plate of 7.4 mm thickness in parent and welded condition and correlate it with the microstructural features [19].

In this work, AA2219 plates welded 11 years ago were used to study mechanical properties for parent and weldments. Micro-hardness, microstructure, fractography analysis of the tensile and fracture toughness tested parent and weldments were compared with the originally reported properties. Three conditions have been studied as a part of the experimental work. Condition A is AA2219-T87 TIG welded and tested in the same year; condition B corresponds to same plate stored at ambient condition, tested after 11 years (condition C refers to same 11 year-old plate which is then TIG welded and tested in the same year). Fig. 10 shows the stress-strain curves of AA2219-T87 welds in condition B at three different temperatures and condition C tested at room temperature. Fig. 11 presents a comparison of the tensile properties from condition A, B and C. It can be observed that the parent metal shows an increase in UTS (4%), YS (8 %) and decrease in % El (30 %). Further, weldment depicts an increase in UTS (20 %), YS (35 %) and decrease in % El (26 %). Additionally, in condition B, strength increased and ductility decreased, compared with condition A at room temperature due to natural aging effect. Weldments (condition B) tested at cryo-temperatures (77 K and 20 K) indicate an increase in both strength and ductility compared with condition A. At 77 K, UTS (26%), YS (40 %) and % El (18%) and UTS (30%), YS (25 %) and % El (18%) for those tested at 20 K. The tensile properties of specimens in condition C are similar to those at condition A. This is a clear indication of natural aging in condition B, significantly affecting the tensile properties.

STEM-HAADF and TEM analysis presented in Fig. 12 revealed the presence of well-oriented densely-populated $CuAl_2$ precipitates (plate-like θ’ and θ” precipitates). The changes in mechanical and fracture properties were correlated to the precipitate distribution, that can be attributed to

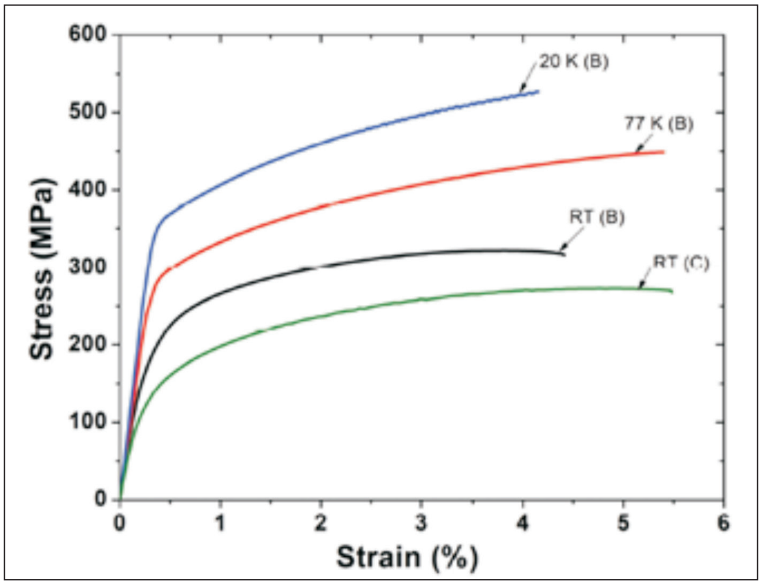

Fig. 10: Stress-strain curves of AA2219-T87 weldments of condition B in three different temperatures and condition C tested at room temperature [19].

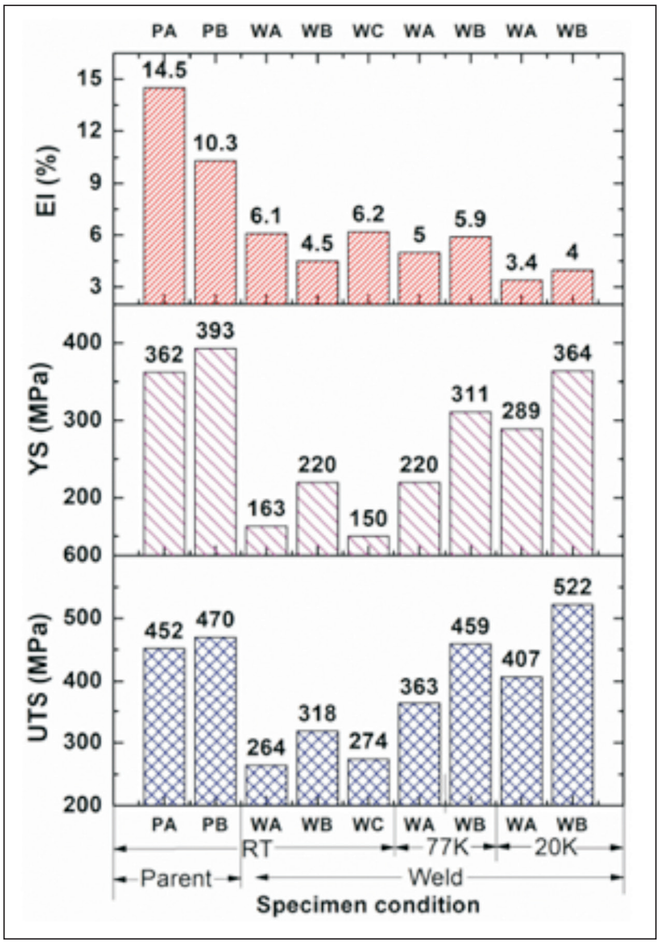

Fig. 11: Comparison of tensile properties of AA2219: present and 11 years ago (PA = parent in condition A, PB = parent in condition B & WA, WB & WC = weld in condition A, B & C respectively) [19].

the natural aging phenomenon, taking place at ambient conditions, during the extended period of storage. The increase in strength of AA2219-T87 is due to the growth of the finer θ” precipitates during natural aging. Since tensile (RT, 77 K, and 20 K) and fracture properties (RT) of welds have improved with no significant reduction in ductility, long-term naturally- aged (up to 11 years) fabricated products of AA2219-T87 are flight-worthy. Growth of the finer precipitates is responsible for the significant changes in mechanical properties [19].

4.2. Mechanical properties of AA2219-T87 friction stir welded joints at RT, 77K and 20K

While there is significant literature on the mechanical properties of TIG welded AA2219-T87 weld-joints at room and cryogenic temperatures, there is no reported literature on the tensile properties of AA2219 FSW joints at room temperature (RT) of different microstructural regions and at cryo-temperatures (77 K and 20 K). In order to qualify the FSW process for fabrication of large-sized propellant tanks, it is essential to evaluate the fracture toughness (K_{Ic} or J_{Ic}) of different microstructure locations from the friction stir welded joints to estimate the available margins for flight certification [20]. In order to evaluate the fracture toughness, a minimum thickness of 15 mm for parent material and 300 mm for FSW welds is required to meet plane strain (K_{Ic}) test conditions according to ASTM B645. The plate thickness used for the fabrication of propellant tanks is only 6 mm. Hence, ASTM E1820

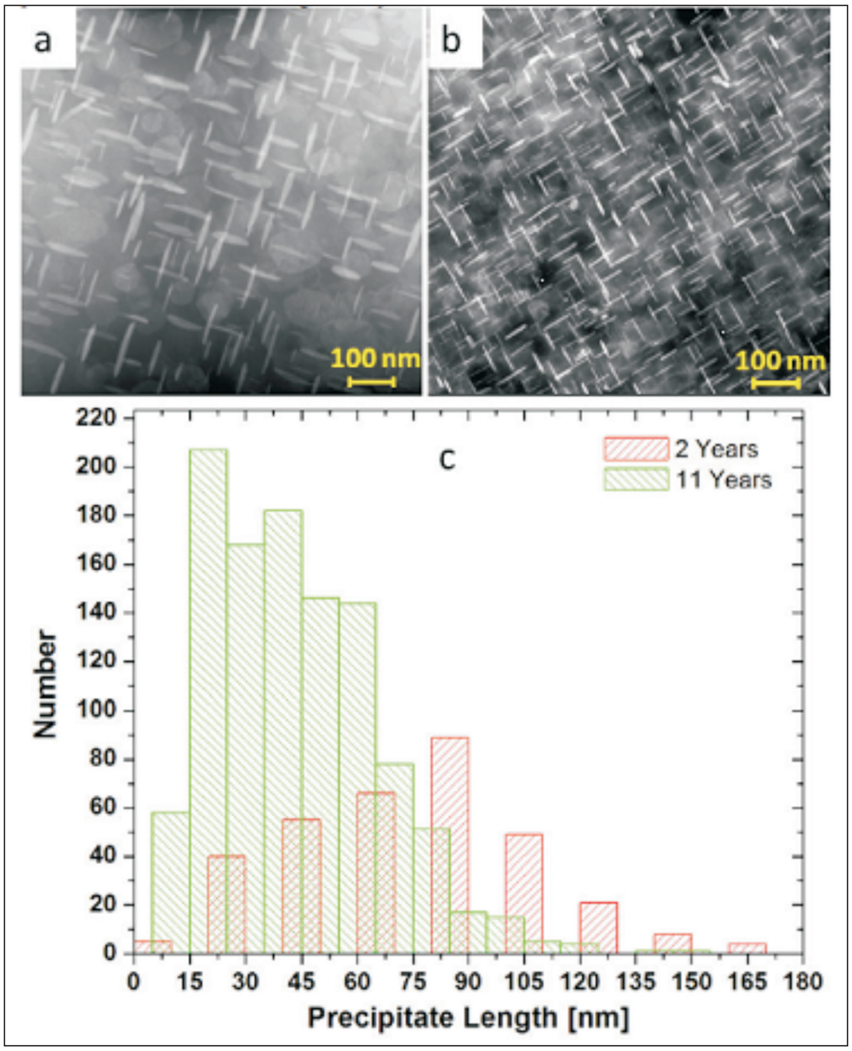

Fig. 12: STEM-HAADF images of AA2219-T87 parent: (a) 2 year old, (b) 11 year old and (c) corresponding number of precipitate vs precipitate length [19].

was considered to calculate the fracture toughness (J_{Ic}). The fracture toughness was evaluated by placing crack at three different microstructure locations (after etching and identifying the zones) viz. middle of the weld nugget zone (WNZ), the thermo-mechanically affected zone (TMAZ) and the heat-affected zone (HAZ). Further, the tensile data from the miniature tensile specimens from the above locations were used to check the validity of J_{Ic}. Since the microstructure of the parent material changes significantly during FSW, it is important to understand the influence of various microstructure zones on the fracture toughness of friction stir welds.

The tensile properties at RT, 77 K and 20 K and localized mechanical properties and fracture toughness are essential for finite element model (FEM) design, analysis and for qualification of the propellant tanks used in launch vehicles. Therefore, it is essential to precisely evaluate the mechanical properties of different regions of FSW joints, to understand how each of these regions behaves under loading conditions for a structural engineer to design the joints and estimate the available design margins. There is no published data on the mechanical properties of individual regions (WNZ, TMAZ and HAZ). Further, the mechanical properties of FSW joints at the cryogenic temperatures (77 K and 20 K) are required for assessing their mechanical behavior under operating conditions. Further, the evaluated FSW joint properties are compared with properties reported for TIG-welded joint of AA2219-T87. Fig. 13 shows different microstructural features of the cross section of AA2219-T87 FSW joint showing the interface between TMAZ and WNZ, onion rings in WNZ and fine recrystallized grains [20] in middle of the WNZ. Fig. 14 shows the scanning electron micrographs of FSW tensile-tested specimens of AA2219 tested at RT, 77 K, and 20 K [20].

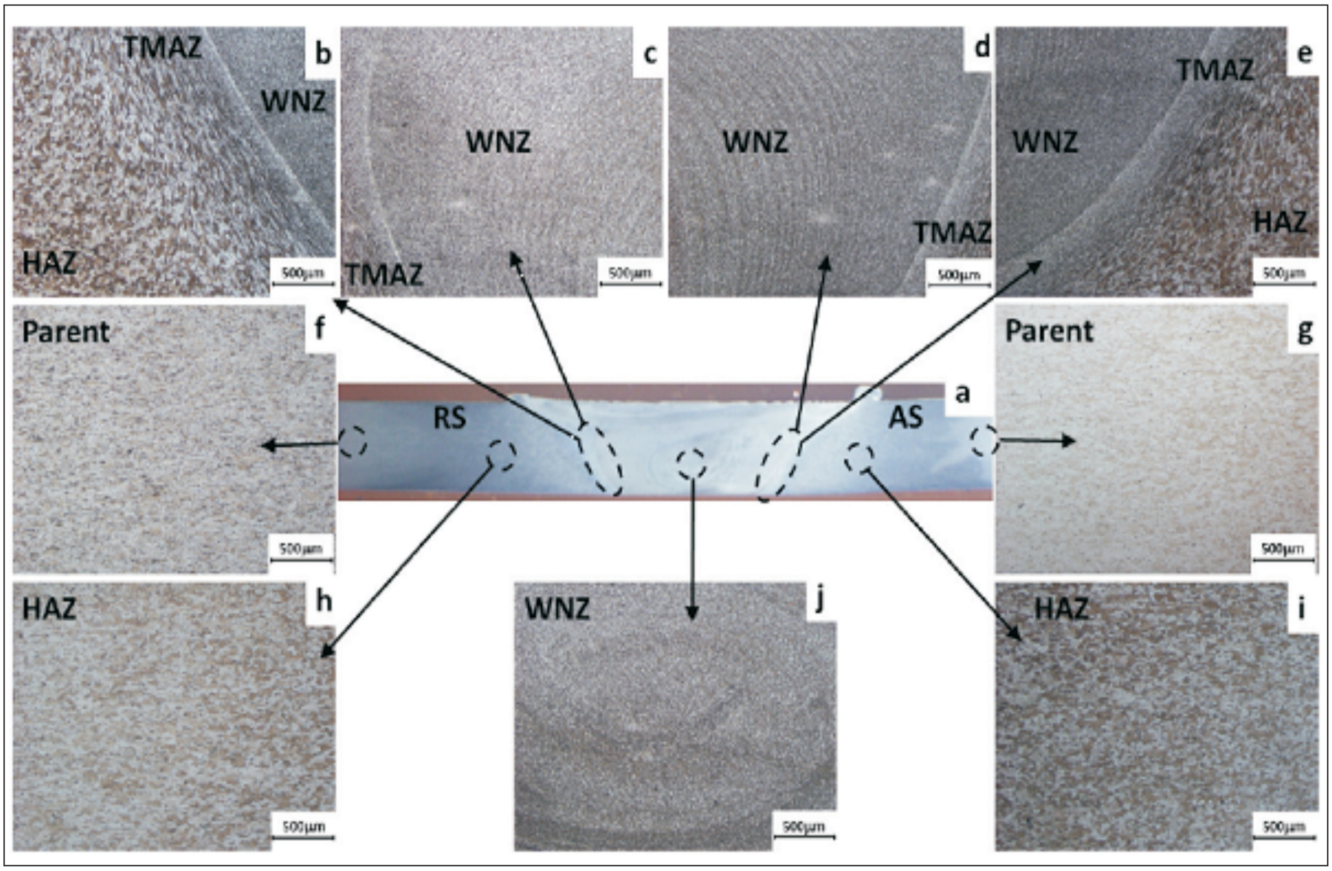

Fig. 13 : Microstructures of AA2219-T87 parent and FSW joint: (a) cross section of FSW joint, (b,e) interface between TMAZ and WNZ, (c-d) WNZ showing onion rings and (j) middle of WNZ showing fine recrystallized grains, (f-g) parent material and (h, i)) HAZ [20].

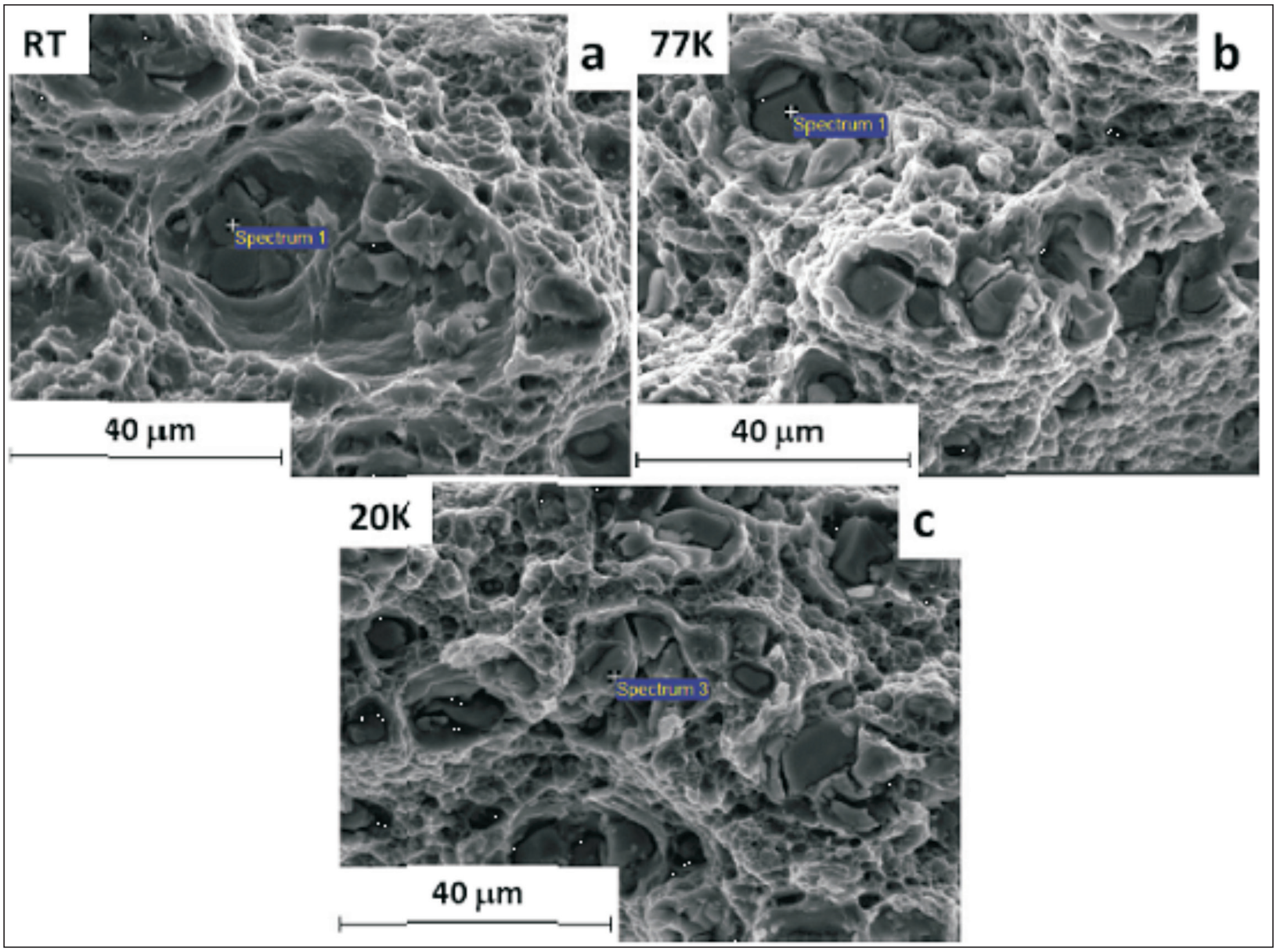

Fig. 14: Scanning electron micrographs and location of chemical composition by EDS of the fracture surfaces of tensile tested specimens of AA2219 in FSW condition: tested at (a) RT, (b) 77 K, and (c) 20 K [20].

Tensile properties of FSW joints were found superior compared to those of the TIG welds at RT, 77 K and 20 K (Fig. 15). It indicates an increase of (79, 99 and 156 MPa) UTS, (43, 33 and 5 MPa) YS and (1.5, 5.6 and 7.5 %) %El compared to TIG welds at RT, 77 K and 20 K respectively. Higher ductility was observed in FSW welds at room temperatures as well as at cryo-temperatures than TIG welded joints. Higher tensile properties in FSW are attributed to the presence of fine equiaxed and recrystallized grains in the weld nugget zone (WNZ) which are significantly smaller than the pre-existing sub-grains in the parent metal. The tensile and fracture properties (Fig. 16) of FSW joints of AA2219-T87 obtained in the present work were compared with tungsten inert gas (TIG) welds of AA2219-T87 reported in literature. It may be noted that the percentage elongation reported in TIG weld was 16 mm GL, whereas in the present work on FSW, it is 2.5 mm GL. Though one-to-one comparison of percentage of elongation is not possible, it was performed for understanding the differences between the two fabrication processes.

Localized tensile properties obtained using miniature specimens extracted from different locations of FSW joints such as WNZ, TMAZ and HAZ were compared with properties obtained from TIG-weld such as weld (WZ), FB and HAZ area; this is presented in Fig. 16(a). Lower strength noticed in FSW was in WNZ region and lower ductility was observed in the TMAZ region. Similarly, in TIG weld, lower strength and ductility were reported in FB region. From this comparison, the superior localized tensile properties of FSW joints are evident against those of the TIG-welded joints.

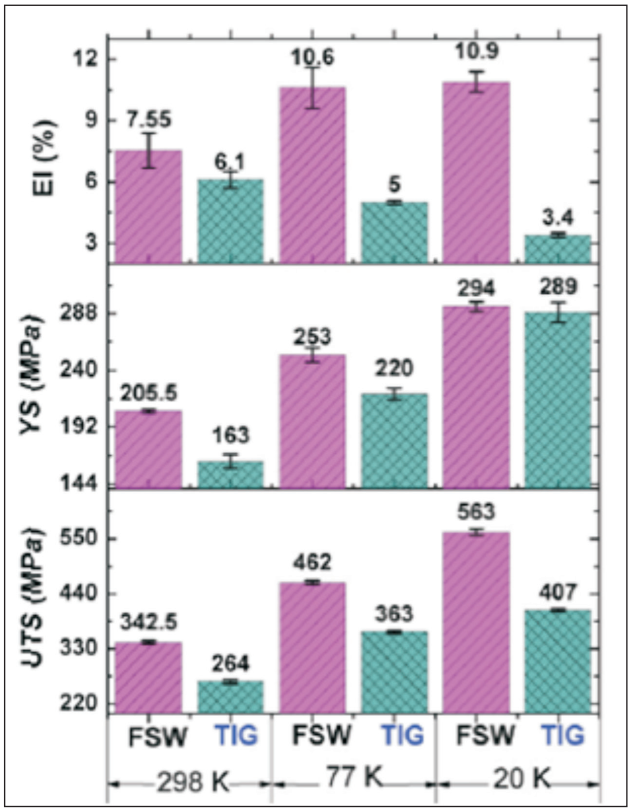

Fig. 15: Comparison of tensile properties of AA2219 in FSW vs TIG welds condition [20].

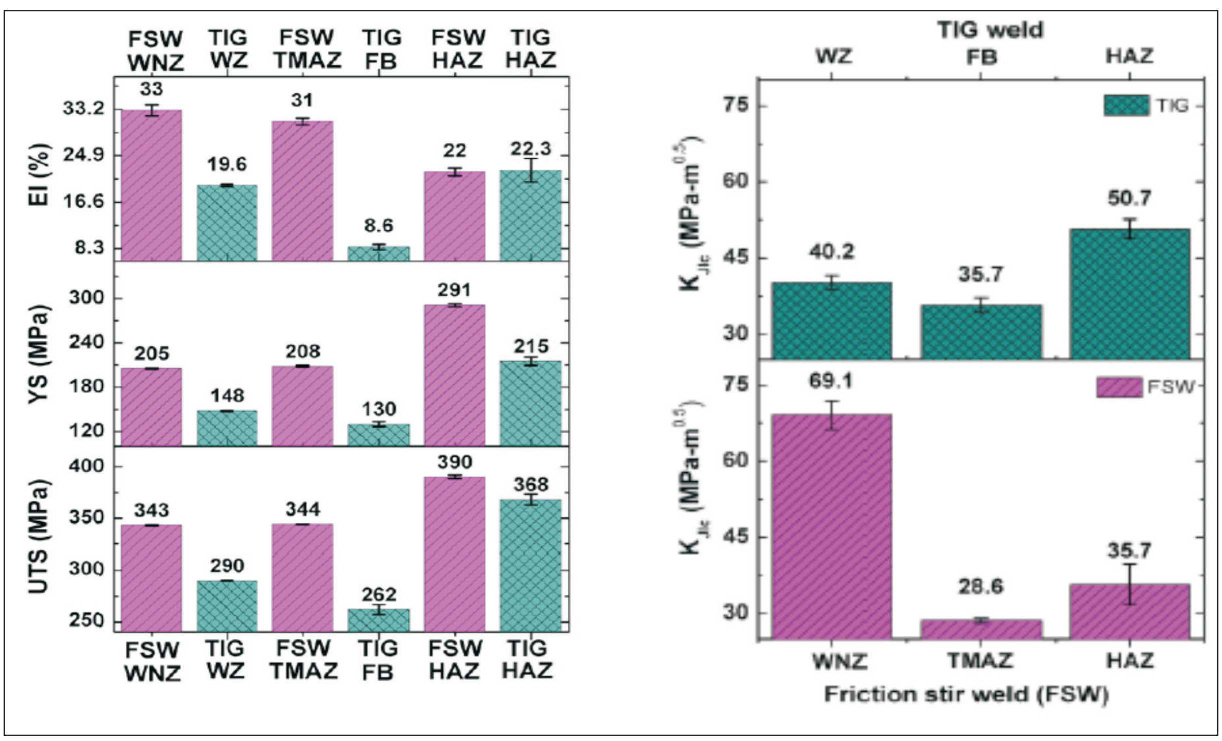

Fig. 16: Comparison of (a) Low Temperature Tensile Properties and (b) RT fracture toughness of AA2219 in FSW vs TIG-weld condition [20].

5. Summary

The challenges posed by the aerospace structural engineers to develop materials that can successfully perform under highly stressed conditions in extremely hostile environments prompted metallurgists to develop technologies to produce materials meeting all desired specifications, against a given standard. The inherent requirements of materials for aerospace applications are high specific strength and specific stiffness, easy fabricability with simple heat treatment, high reliability, with low lead times for realization. In order to meet these requirements, high strength steels, age-hardenable aluminum alloys, titanium alloys and magnesium alloys are used extensively, mostly in their peak aged tempers, wherever applicable. However, these materials should be handled carefully as they could pose several challenges during service under hostile environments. Some of the aerospace materials development activities undertaken are highlighted: such as 3rd generation Al-Cu-Li alloys, Cu-Cr-Nb alloys and, Boron-added titanium alloys. Further, a number of studies were conducted as a part of the on-going developmental activities from which two examples (i.e. one on the effect of long term storage of qualification of propellant tanks and another on friction stir welding of AA2219) are presented. It is believed that the details shared in this lecture are thought provoking and are capable of motivating young metallurgists to take research as their profession and tackle the consequential challenges.

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Recent Developments International

Researchers turn waste byproduct asphaltene into graphene

Researchers from Rice University, University of Calgary, South Dakota School of Mines and Technology, and University of Washington have managed to turn a waste material called asphaltene (a byproduct of crude oil production) into graphene.

Rice University's Muhammad Rahman, an assistant research professor of materials science and nanoengineering, is employing Rice's unique flash Joule heating process to convert asphaltenes instantly into turbostratic (loosely aligned) graphene and mix it into composites for thermal, anti-corrosion and 3D-printing applications. The process makes good use of material otherwise burned for reuse as fuel or discarded into tailing ponds and landfills. Using at least some of the world's reserve of more than 1 trillion barrels of asphaltene as a feedstock for graphene would be good for the environment as well.

"Asphaltene is a big headache for the oil industry, and I think there will be a lot of interest in this," said Rahman, who characterized the process as both a scalable and sustainable way to reduce carbon emissions from burning asphaltene.

Asphaltenes are 70-80% carbon already. The Rice lab combines it with about 20% carbon black to add conductivity and flashes it with a jolt of electricity, turning it into graphene in less than a second. Other elements in the feedstock, including hydrogen, nitrogen, oxygen, and sulfur, are vented away as gases.

"We try to keep the carbon black content as low as possible because we want to maximize the utilization of asphaltene," Rahman said.

"The government has been putting pressure on the petroleum industries to take care of this," said Rice graduate student and co-lead author M.A.S.R. Saadi. "There are billions of barrels of asphaltene available, so we began working on this project primarily to see if we could make carbon fiber. That led us to think maybe we should try making graphene with flash Joule heating."

Assured that Professor James Tour's process worked as well on asphaltene as it did on various other feedstocks, including plastic, electronic waste, tires, coal fly ash and even car parts, the researchers set about making things with their graphene. Saadi, who works with Rahman and Ajayan, mixed the graphene into composites, and then into polymer inks bound for 3D printers.

"We've optimized the ink rheology to show that it is printable," he said, noting the inks have no more than 10% of graphene mixed in. Mechanical testing of printed objects is forthcoming, he said.

Source: ASM International

American Elements creates novel nanoscale electrolyte for next-generation lithium batteries

American Elements announced that its engineers have invented a novel nanoscale electrolyte material for use in cutting-edge lithium-sulfur battery technology. The electrolyte is a ceramic compound of lithium, lanthanum, and zirconium oxide nanoparticles that is energy-dense and stable in a wider range of temperatures than typical electrolytes used in commercial lithium-ion batteries.

"With this significant invention, American Elements is demonstrating its commitment to fostering innovations in efficient energy storage technologies that help address performance and safety concerns about the current generation of lithium-Ion batteries" said Michael N. Silver, Chairman & CEO of the company.

Source: ASM International

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News Updates Domestic

'India's April-December finished steel exports drop 54% year on year'

India's exports of finished steel more than halved during the first nine months of the fiscal year that began in April 2022, according to the latest government data seen by Reuters.

The exports fell 54.1% to 4.74 Mt between April and December, as consumption dropped in major global markets, and mills struggled to revive shipments after the recent withdrawal of an export tax. However, the world's second biggest producer of crude steel was a net exporter of the alloy during the April-Dec. period.

In May, New Delhi raised export tax by 15% on eight steel intermediates, hitting major steelmakers, who had hoped to boost global market share after Russia's invasion of Ukraine, but the higher duties made shipments unattractive.

The duties were scrapped in November, but mills have since complained about difficulties in recovering share in traditional markets, including Europe.

India's finished steel output increased 5.7% to 87.9 Mt and consumption went up by 11.5% to 85.5 Mt between April and December.

India imported 4.4 Mt of finished steel during the period, up 27.4% from a year earlier. Crude steel production was up 5%, at 92.5 Mt.

The Economic Times

Emissions dip, Govt may make 'green steel' mandatory: Jyotiraditya Scindia

Union Minister of Steel Jyotiraditya Scindia told Rajya Sabha that the government was considering mandating the use of "green steel" in government projects. He said emissions from the steel industry have been brought down by 15% between 2005 and 2022 and Centre targets an additional 10% reduction in emissions by 2030. Energy consumption per tonne of steel produced has also come down as well as emission intensity in terms of CO_2, he added.

Responding to a question from NCP MP Vandana Chavan on carbon emissions in the steel sector, the Minister said the government has put into place a short-term plan, as well as medium and long-term targets to deal with the issue.

"The short-term plan looks at reduction of carbon emissions through energy and resource efficiency in renewable energy. The medium-term plan (2030-47) looks at Carbon Capture Utilization and Storage as well as usage of possibly green hydrogen. And, the long-term plan (2047-70) looks at a complete move over from ore-based and coal-based to much more technological innovations to come down to net zero," Scindia told the Rajya Sabha.

"The iron and steel sector is projected to grow five times in the next two decades. The steel sector is extremely energy and resource intensive. And, in its present form, it is highly polluting. Today, the production of one tonne of steel means emission of three tonne of carbon dioxide; whereas, globally this is only 1.4 tonne," said Chavan.

"...our current average emission intensity is 2.55 tonne CO_2, per tonne of crude steel, compared to about 1.95 tonne of global average... From 2005 to 2022, we have brought down emissions by almost 15 %," Scindia said. He further said India has now become the second largest steel producer in the world in the last eight years "doubling our capacity from 150 Mt to 154 Mt worth of production".

https://indianexpress.com/

Andhra Pradesh government clears decks for JSW Steel plant in Kadapa

In a major development, the state government has given green signal for JSW Steel to set up an integrated plant in Andhra Pradesh's Kadapa district.

The State Investment Promotion Board (SIPB) chaired by chief minister YS Jagan Mohan Reddy cleared the JSW proposal to set up the steel plant with an investment of Rs 8,800 crore.

Initially, the state government wanted to set up the plants from its own resources. Taking the financial constraints into consideration, the state government has roped in the steel giant JSW to set up the plant. The company will invest nearly Rs 3,300 crore to complete the first phase to produce 1 Mt of steel.

The new steel plant is coming up at Sunnapurallapalle village of YSR Kadapa district. The JSW would take up the project in three phases and it would produce 3 Mt of steel at the end of the final phase of the project.

"This steel plant is going to be the game-changer to the economic growth of the entire Rayalaseema region, particularly YSR Kadapa. It will create huge employment directly and indirectly," said the chief minister.

The Times of India

Jharkhand: 110 m tall chimney of Tata Steel plant demolished in 11 seconds

A 110-metre-high, 27-year-old chimney at Tata Steel's Jamshedpur plant was demolished in 11 seconds with the implosion method in a safe and environment friendly way, informed Vice President of Tata Steel Plant, Avneesh Gupta.

"The 27-year-old 110-metre-high chimney of battery number 5 of the Jamshedpur plant was demolished using the implosion method, which made the demolition process safe for workers. It also saved time and was environment friendly too. The smoke tower was demolished within 11 seconds," Avneesh Gupta said.

The task of demolishing the chimney of the coke plant's closed batter was given to South Africa's Edifice Engineering India supported by J Demolition Company. It is the same company that demolished Noida's twin towers on August 28. The towers, Apex (32 floors) and Ceyane (29 floors), which are taller than the Qutub Minar in the national capital, were 100 metres tall and were brought down with explosives weighing at least 3,700 kg, in the biggest ever planned tower demolition bid.

"Before the dropping down of this chimney, a 75-year-old, a repair shop of the coke plant of height 2 metres was demolished as rehearsal," he added. Speaking at a press conference, the Vice President of the Tata Steel Plant also said that the company is planning to remove all the old plants and bring in new plants.

The Economic Times

Tata Steel will continue to invest in Odisha: CEO Narendran

Tata Steel which has make investments of over Rs 75,000 crore in Odisha will continue to invest in the state which has 25 per cent of India's total steelmaking capacity, its MD & CEO T V Narendran said. Narendran made the remarks at the 'Make in Odisha Conclave 2022' in Bhubaneswar.

"The Tata group of companies, and more specifically Tata Steel, has invested over Rs 75,000 crore in Odisha in the last five years. We will continue to invest to support the growth in Odisha," the official said.

Over the last few years in Odisha, Tata Steel has not just built its plant in Kalinganagar, but has also acquired several assets which include Neelachal Ispat plant, he said. According to Narendran, Tata Steel is the largest steel manufacturer in Odisha producing about 9 Mt of steel annually.

"We plan to double this over the next few years as we expand in all our locations in Odisha. Odisha accounts for 1/4th of the steel capacity in the country today," he said. Steel Minister Jyotiraditya Scindia said India's total steel making capacity has touched about 150 Mt mark.

The Economic Times

SMS group and Tata Steel sign MoU to decarbonise integrated steel plants

Tata Steel, one of the world's leading steel producers, has signed a memorandum of understanding with SMS group to reduce carbon emissions at Tata's integrated steel plants across India. SMS group will contribute its leading technological expertise in designing, supplying, and commissioning plants with significantly lower CO_2 emissions.

Burkhard Dahmen, CEO and Chairman of SMS group, said: "Our companies have a common goal to reduce carbon emissions from iron and steel production, as the industry is not only key to economic prosperity, it is also one of the largest CO_2 emitters. We are therefore very proud to team up with Tata Steel and are committed to supporting the company with its decarbonisation roadmap. This represents an important contribution in the fight against climate change and is beneficial for the Indian economy as a whole and especially for the communities located around the steel plants.”

The MoU with Tata Steel is another milestone in SMS group’s mission to turn metals green. SMS can draw on its unique positioning as an expert in all major metals, as a supplier of the complete process chain, including all upstream and downstream processes plus recycling, and as a provider of services covering automation, digitalisation, and consulting.

https://greensteelworld.com/

Coking coal, iron ore may not be viable for steel making in future: Scindia

Union minister Jyotiraditya Scindia urged the domestic steel industry to adopt low-carbon emitting steel-making processes, while cautioning that key raw material coking coal and iron ore may not be a viable option in the future based on an ESG parameter.

The comments have come at a time when India moves to double its steel-making capacity to 300 Mt.

“From the second largest producer of steel, we must also become responsible producers of steel in the world. There will come a time in the near distant future when today's raw materials be it iron ore or coking coal will no longer be a viable option not necessarily from a cost structure parameter but from an environmental, social, and governance (ESG) parameter," Scindia said at an event.

The minister said that environmental concerns could arise in future and the government and the private sector will have to work together to prepare for that "eventuality today". “The industry can look for options like the use of renewable energy that can cut CO_2 emissions, pelletization. In India, every 1 per cent increase in Fe (iron) content results in 1 per cent lower consumption of coke in the process, and the less coke you consume, the lesser CO_2 emissions occur," the minister said.

Options of using plastic, not as raw material but in the process of the value chain and use of scrap in steel making can be looked at.

India uses 20 per cent of scrap in steel production, he said adding that 26 Mt of scrap is generated domestically and 4 Mt is imported. The government has been pushing for the usage of renewable energy sources besides other low-carbon generating technologies in the steel sector in various processes of manufacturing.

The steel minister was speaking at the launch of Kalyani Group's first green steel brand 'Kalyani FeRRESTA'. On the green steel brand, Kalyani Steels Managing Director R. K. Goyal, the product is the “country's first green steel product which has been produced through usage of green energy.” It is a long steel product to be used by industries such as defence aerospace etc., he said.

Business Standard

JSW Steel's combined output in Q3 grows 17 pc to 6.24 Mt

JSW Steel said its combined crude steel production rose 17 per cent to 6.24 Mt during October-December period of 2022-23. The combined production during the year-ago quarter was at 5.35 Mt, JSW Steel said in a statement.

“JSW Steel reported its group combined crude steel production at 6.24 Mt for Q3 FY23 registering a growth of 17 per cent y-o-y (year-on-year), including the production at jointly controlled entities," it said.

Its standalone output rose 20 per cent to 6.06 Mt in Q3 from 5.05 Mt in the year ago period.

According to the company, the combined production includes output of jointly controlled entities Bhushan Power & Steel Ltd (BPSL) and JSW Ispat Special Products Ltd (JISPL), and offshore entity JSW Steel USA Ohio.

JSW Steel is among India's top six steel making companies.

The Economic Times

Turkish steelmakers fear India’s entry into the local steel market

The abolition of the export duty on steel in India may increase the import of cheaper products to the domestic market of Turkiye. Steel companies in Turkiye fear an increase in the import of cheaper steel products from India into the country after the Indian authorities cancelled the export duty on steel.

Turkish steelmakers are worried about the lifting of tariffs by one of its biggest rivals, India, at a time when high energy costs are hampering the competitiveness of local steelmakers.

Steel production in Turkiye in October 2022 decreased by 17.8% compared to October 2021 – to 2.9 Mt. The negative indicator reflects the increase in energy prices in the country, as well as low demand in Turkiye's target markets due to fears of a recession.

At a time when rising costs continue to weigh on local producers, the removal of tariffs in India could further worsen the situation. The corresponding decision of the Indian authorities will probably put pressure on the prices of steel products in Turkiye, since Indian steelmakers are the largest suppliers of rolled steel to the Turkish market.

https://gmk.center/

SAIL expects Q3 realisations to sustain at Q2 levels due to lower coal cost

PSU steel major SAIL is expecting some benefits of lower coking coal price to accrue in its Q3 numbers (October- December), but overall realisations may not change much over Q2, Anil Kumar Tulsiani, the company's Director (Finance) said.

Long products could see prices firming up a bit, he said adding that price of steel – which peaked in April – has now seen a 25–30 per cent decline in the domestic market. Flat products are witnessing a much "greater adverse impact".

Interestingly, the second half of the fiscal are seen as seasonally busy quarters for the steel industry.

Q3 outlook

"The realisations may not be better as compared to the second quarter. We may try to keep it at the same levels in the third quarter," Tulsiani said during a recent analyst call.

SAIL's volume sales stood at 7.36 Mt in the first half of FY23, lower than the 7.61 Mt in the same period last year. Revenue rose 6 per cent y-o-y to ₹50,275 crore; while EBITDA dropped 73 per cent to ₹3,780 crore.

Average sales price stood at around ₹62,000 per tonne, down one per cent y-o-y and lower by 18 per cent quarter-on-quarter (q-o-q) .

The SAIL management expects FY23 production to be in the range of 17 – 17.5 Mt and sales to be around 16 – 16.5 Mt. Benefits of lower coking coal procured in August– September will accrue in Q3FY23.

Coking coal costs

A benefit of ₹5,000 per tonne is expected on coal import cost during the current quarter.

However, after an initial decline, coal prices are again on the rise and this could bring about an impact in Q4.

"Impact of coal prices moving up, will come in the fourth quarter (January –March). When we import from the USA, it is round about 3 months and it works out round about 2 to 3 months for the Australian coal. So, we will be getting the benefit of the imports which we have made in the month of say, August and September. May be whatever coal we are procuring now, it will be shifted over to the fourth quarter," he said.

https://www.thehindubusinessline.com/

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Chapter Activities Angul, Hazira, Bhubaneswar, B E College

Angul Chapter

The EC meeting of IIM Angul Chapter was held on June 10, 2022 where the chapter bearers were selected :

Chairman → Mr. Ambika Prasad Panda

Secretary → Sk Macksut Ali

Treasurer → A.K. Agasti

The Audience

Hazira Chapter

IIM Hazira Chapter organised a technical session on a hybrid mode on November 9, 2022. The topic of the session was "Processing-induced defects in steel castings: Prediction and control using numerical, criterion and AI models". Prof. Shyamprasad Karagadde, Associate Professor, Mechanical Engineering, IIT Bombay was the speaker on the occasion. The session was physically attended by 105 participants from various industries like L&T, Arcelor Mittal Nippon Steel India (AMNSI) and student participants from Sardar Vallabhbhai National Institute of Technology (SVNIT) Surat. The session was well appreciated by the participants.

Prof. Shyamprasad Karagadde delivering the lecture

Photo Session

Bhubaneswar Chapter

A refresher course on "Fundamentals and Advances in Mineral Engineering (FAME-2022)" was organised by the IIM Bhubaneswar chapter in association with CSIR-IMMT, Bhubaneswar from December 19 to 23, 2022. The inaugural address was delivered by the Chief Guest Sri. S. C. Mishra, Ex-ED, IREL Ltd. Scientists of CSIR-IMMT and professionals from academia and industries imparted training to 22 participants from various industries, academics.

Sri. S. C. Mishra delivering his inaugural address

Prof. T. C. Rao on 22nd December 2022 addressing the participants

B E College Chapter

The EC meeting of IIM B E College Chapter was held on December 28, 2022 where the chapter bearers were selected:

Chairman → Prof. Tapendu Mandal

Secretary → Dr. Sukumar Kundu

Treasurer → Dr. Gautam Anand

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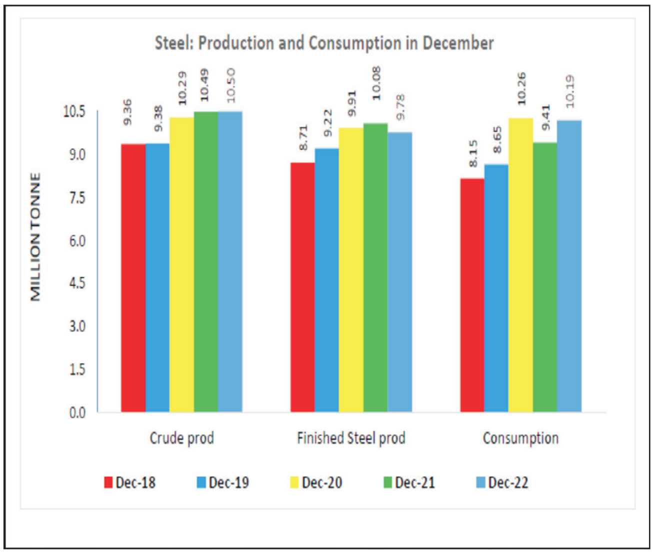
Summary on Iron & Steel December 2022

Production and Consumption Scenario:

i. A comparison of production and consumption of steel during the month of December over five years indicate that production of crude as well as consumption of finished steel during December'22 is highest in five years. However, the production of finished steel declined over CPLY as may be seen from following graph:



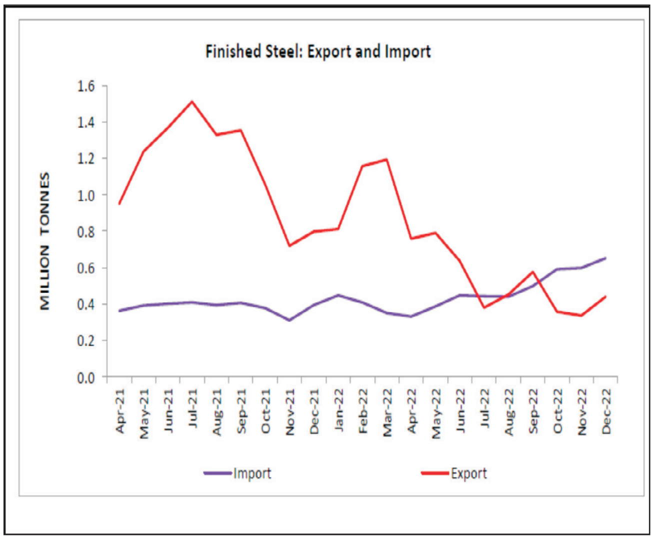
ii. Production of crude steel in December'22 at 10.50 MT increased by 0.1% over CPLY and 0.6% by M-o-M.

iii. Production of finished steel in December'22 at 9.78 MT decreased by 3.0% over CPLY and 0.5% by M-o-M.

iv. Consumption of finished steel in December'22 at 10.19 MT increased by 8.3% over CPLY and 6.5% by M-o-M.

v. Inventories of the finished steel with the steel producing companies at 10.0 MT at the end of December'22 decreased by 2.0% M-o-M but increased by 18.1% over CPLY.

Export-Import Scenario: The month-wise trend in export and import of finished steel during recent months shows that except for July'22, India's export during a month has consistently exceeded import during that month. During the month of December'22 the export from India decreased and imports increased as may be seen from the graph below:



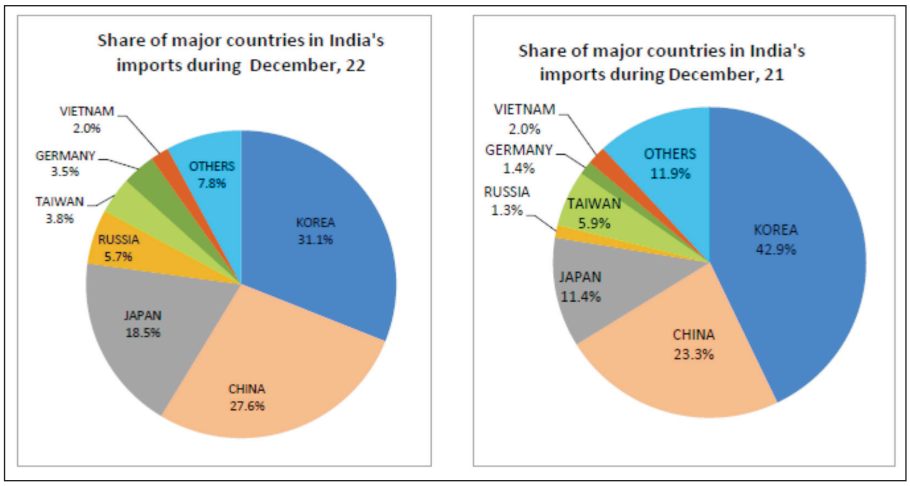
i. Export of finished steel in December'22 at 4.42 LMT increased by 30.8% M-o-M but decreased by 44.6% over CPLY while import at 6.53 LMT increased by 8.8% M-o-M and by 65.3% over CPLY. During April-December'22, exports at 47.41 LMT declined by 54.1% while imports at 44.04 LMT increased by 27.4% over CPLY.

ii. In November, India's export was lower than its imports and it was a net importer of finished steel during the month.

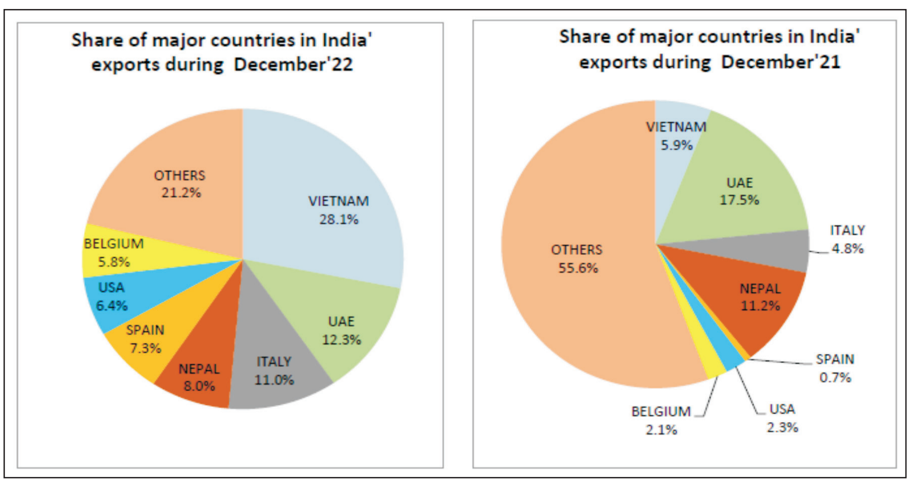
iii. Share of China, Japan, Russia, Germany, France, Nepal and Oman increased in total steel import of India in December'22 as compared to December'21 while share of Korea and Taiwan declined over this period as may be seen from the following graph (a):

iv. Share of Vietnam, Italy, Spain, USA, Belgium, Bangladesh, Bulgaria and UK was higher in total steel export from India in December'22 as compared to December'21 while share of UAE and Nepal declined over this period as may be seen from the following graph (b):

(a)



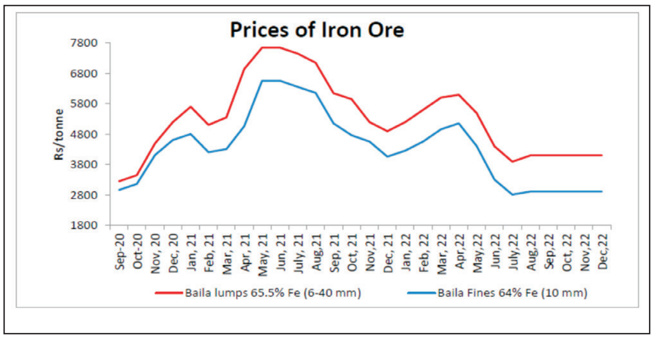
(b)



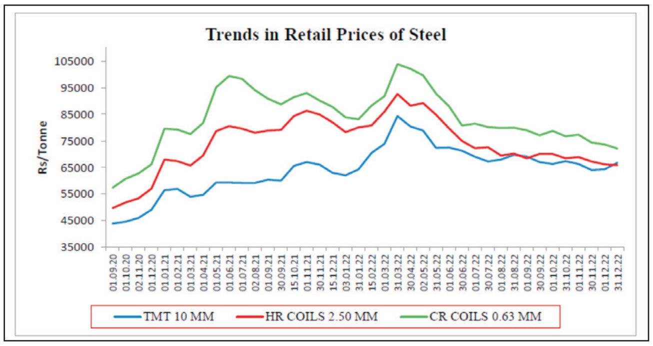
Price scenario: Prices of iron ore, hit its peak in May-June'21. Its prices followed a declining trend since July'21 till December'21 but started increasing again from January'22 and the uptrend continued till April'22. The prices of iron ore which was declining since April have stabilized during recent months with the prices in the month of December'22 in previous month as may be seen from the graph below:

i. During the month of December'22, prices of iron ore lump and fines at Rs. 4100/tonne and Rs. 2910/tonne respectively remained at the same levels as their respective prices in November'22.

ii. The prices of CRC, HRC and Rebar, peaked in March'22 and started moderating thereafter. The reduction in the prices may partly be attributed to decline in the cost of inputs. Prices of Australian coking coal declined to the level of below USD 200/tonne by the end of July, 2022 as against its peak of about USD 650/tonne recorded in March, 2022. Prices of iron ore also declined. In addition, declining international prices of steel and policy intervention in terms of imposition of suitable modifications in tariff lines have also contributed to this trend of moderation in the domestic prices of steel. However, prices of raw material used for Steel making specially Coking Coal have seen some uptick in prices during Mid-August and September'22 when compared to July'22-early August'22. The prices of HCC Coking coal FOB Australia increased from USD

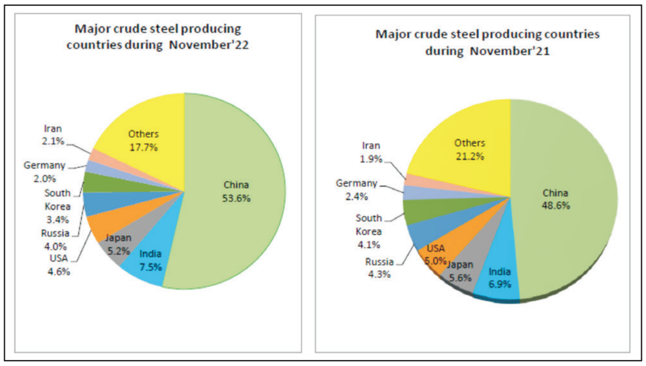


188/tonne on 3rd August, 2022 to USD 274/tonne in September'22 and then moderated somewhat to USD 251/tonne during the month. Such trend in prices of input resulted in steel prices showing a declining trend during the month with prices of TMT, HRC and CRC during the month as may be seen from the following graph depicting trend in prices of steel product categories viz., Rebar, HRC and CRC.



iii. The retail prices for Rebar (10mm) in Mumbai on 31st December'22 at Rs. 66750/tonne were 3.8% higher than their respective prices at the start of the month. However, the prices for HRC (2.50mm) at Rs. 65780/tonne and CRC (0.63mm) at Rs. 72100/tonne respectively were 0.6% and 2.1% lower than their respective prices at the start of the month.

The global production of crude steel decreased by 2.6% in November'22 over CPLY which is majorly due to decrease in production in Japan, USA, Russia, South Korea, Germany and Turkey. China, India, Iran and Brazil among the major producing countries (with production of 1 million tonne for the month) recorded an increase in production in November'22 over November'21. As regard the share of major steel producing countries in the global production of crude steel, it is seen that due to differences in contribution to global production, share of China, India and Iran increased during November'22 while that of Japan, USA, Russia, South Korea, Germany, Turkey and Brazil declined during this period as may be seen from the following graph:



Source : https://steel.gov.in/

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Seminars & Conferences

Refractories in Iron and Steel Industries (REFIS 4.0)

The international conference on "Refractories in Iron and Steel Industries (REFIS 4.0)" was organised by Bokaro Steel Plant in association with The Indian Institute of Metals, Bokaro Chapter and the Indian Ceramic Society, Kolkata during 23rd -24th September 2022 at Bokaro Steel City, Jharkhand. The Conference aimed to bring together Iron & Steel Industry, Manufacturer of Refractories, Leading academic scientists, Researchers and Research scholars to exchange and share their experiences and research results on all aspects of Refractories used in Iron and Steel Industry.

The dignitaries are on the dais

It also provided a premier interdisciplinary platform for researchers, practitioners and educators to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of Refractories during the current changing global scenario of Refractories and Raw materials.

Technical Program of the conference included a plenary session and eight parallel sessions with the topics related to Emerging Technology for Refractory in Refractory, Refractories for Iron zone, Refractories for Steel zone and Refractories for secondary steel refining and casting and Quality assurance. Altogether more than 50 papers were presented thro' hybrid mode by experts chosen from industry, R&D and academia spread over one and half day. A reasonable number of graduate students have also been invited to take part in the conference, present their work and interact with the peers. Each session was chaired by a professional with long working experience in refractories related to Iron and steel industries.

A compilation of the technical papers presented in the conference was published by the panel of editors under ISBN registration as Proceedings of Conference enumerating the experimental & practical experiences of the manufacturers and consumer industries. The Souvenir of the conference and the Proceedings of the conference, both were released during the opening ceremony.

The audience

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