

**Metal Additive Manufacturing**  
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**Lecture 28**

**Additive Manufacturing of Metal Matrix Composites (Part 3 of 4)**

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Welcome to the next lecture on additive manufacturing assisted for metal matrix fabrication. In the past, we have gone through conventional different ways of making metal matrix composite. Then, we studied how additive manufacturing laser assisted is useful in making such metal matrix composites. The big difference between conventional and additive manufacture metal matrix composites, is its microstructure.

Microstructure tries to dictate the property. Then, we studied various matrixes which are used for making composites, amongst them, iron, aluminum, titanium and nickel are very prominently used. How do you decide the matrix? The matrix is decided based upon the ductility it has, density and wear resistance hardness. So, all these things try to help in choosing the matrix.

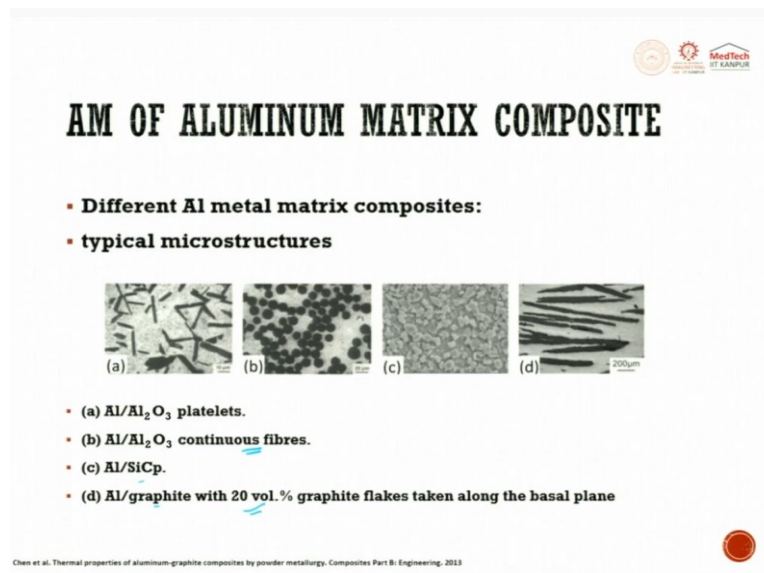
Then for the reinforcements, predominantly for metal matrix composites, it is made of particulates. We saw how is TiC, TiN, B<sub>4</sub>C, WC and VC all these are used for making reinforcement in the metal matrix. We discussed about iron matrix then we discuss about titanium matrix and the latest research which is going on is titanium reinforced with Hydroxyapatite.

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Now, in this lecture as part three, we will try to see two more matrixes. One is aluminum, the other one is nickel. Aluminum is very much common and very popular amongst metal matrix composites. For two simple reasons. One, it is lightweight, it is cost effective. And third it is ductile and you can tweak its properties to your own requirements easily. So, aluminum finds a lot of applications in automobile, aerospace, entertainment industry and in also the biomedical applications in terms of instrumentation. They find a lot of applications.

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Next is Nickel, wherever it is high temperature and where they do not bother much about density, they go for nickel matrix composites. When we talk about metal matrix composites where aluminum is the matrix so, we see various types of microstructures. We see here

alumina platelets type, then we see here continuous fiber alumina through which the metal is squeeze casted.

Then we try to see silicon carbide where alumina is the matrix, the next one is going to be graphite with 20% volume fraction, where graphite flakes taken along the basal plane. So, these are the different types of microstructures, you can also have continuous fiber, these fibers are ceramic fibers, they are again made as a preform and they can use it for squeeze casting.

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**AM OF ALUMINUM MATRIX COMPOSITE**

- **Al-Fe<sub>2</sub>O<sub>3</sub> Composite**
  - Fe<sub>2</sub>O<sub>3</sub> is another low-cost reinforcement, which minimizes the energy required to fabricate AMC in laser-based AM techniques.
  - The in-situ reaction between the mixture of Al and Fe<sub>2</sub>O<sub>3</sub> can produce Fe<sub>3</sub>Al and Al<sub>2</sub>O<sub>3</sub> in Al matrix,

$$8\text{Al} + 3\text{Fe}_2\text{O}_3 \rightarrow 2\text{Fe}_3\text{Al} + 3\text{Al}_2\text{O}_3 + \text{heat} \quad (22)$$

- The stoichiometric reaction shows that the laser beam ignites the additional heat and stimulates thermite interactions through the AM process.
- This exothermal excess heat of in-situ reaction lowers the laser energy required to melt powder mixtures, followed by solidifying the composite melt.

**AM OF ALUMINUM MATRIX COMPOSITE**

- **Al-Fe<sub>2</sub>O<sub>3</sub> Composite**
  - The amount of Fe<sub>2</sub>O<sub>3</sub> has a substantial impact on the hardness, density, and surface roughness.
  - It can control the energy discharge in the reaction and, thereby, form the surface profile.
  - The higher content of Fe<sub>2</sub>O<sub>3</sub> does not affect the composites' densification property but can improve the hardness through excellent interfacial bonding and uniform distribution of reinforcements within the matrix

*Handwritten notes:*

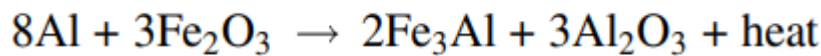
Metal matrix composite

Laser parameter

- Uniform dispersion of reinforcement
- Good interfacial bonding

When we try to mix iron oxide in aluminum, so, we can also make such composites. Fe<sub>2</sub>O<sub>3</sub> is another low-cost reinforcement which minimizes the energy required to fabricate AMC in laser based additive manufacturing techniques. The in-situ reaction, whatever it is, so that

means to say you do not make iron powder, you try to have ingredients and that will try to reinforce and then get you.



So, the stoichiometric reaction shows that the laser beam ignites the additional heat and simulate thermite interaction through the AM process. The exothermal excess heat of in situ reaction lowers the laser energy required to melt powder mixture followed by solidifying the composite melt.

So, this is very important exothermal excess heat, then stoichiometric reaction is maintained. The amount of iron oxide has a substantial impact on the hardness, density and surface toughness. It can control the energy discharge in the reaction and thereby form a surface profile.

The higher content of iron oxide does not affect the composite densification property, but can improve the hardness through the excellent interfacial bonds. Interfacial bond is also one important thing as far as metal matrix is concerned. Now that we have seen some amount of metal matrix's basics, let me list out what all are expected from a metal matrix composite.

So, the first thing is it should have uniform dispersion of reinforcement. The second thing is it should have good interfacial bonding. These two are very important. So, if you want to have this good interfacial bonding and uniform dispersion so, you must vary the laser parameters to get the required output.

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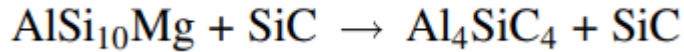
**AM OF ALUMINUM MATRIX COMPOSITE**

- **AlSi<sub>10</sub>Mg-SiC Composite**
  - The lower hardness and poor wear properties of Al alloys can be improved through the incorporation of hard particles such as SiC, Al<sub>2</sub>O<sub>3</sub>, and TiB<sub>2</sub> into the matrix

$$\text{AlSi}_{10}\text{Mg} + \text{SiC} \rightarrow \text{Al}_4\text{SiC}_4 + \text{SiC} \quad (23)$$

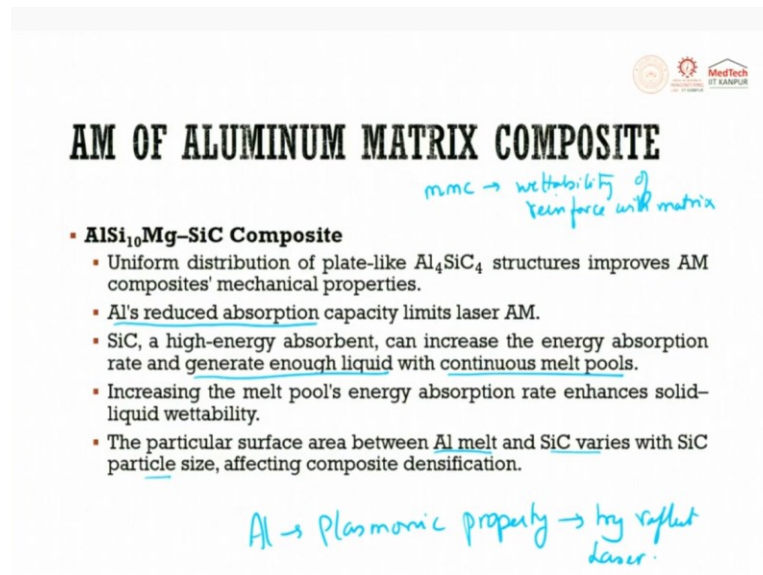
- In-situ reaction between Al and SiC forms Al<sub>4</sub>SiC<sub>4</sub> by forming irregular nuclei at the contact.
- As the reaction progresses, the nuclei become plate-like.

AlSi<sub>10</sub>Mg with SiC composite, lower the hardness, poor wear properties of aluminum alloy can be improved through the incorporation of hard particles such as Si<sub>3</sub>, SiC, Al<sub>2</sub>O<sub>3</sub> and TiB<sub>2</sub> into the matrix.



So, this becomes the matrix and this becomes the SiC reinforcement. In situ reaction between Al and SiC forms Al<sub>4</sub>SiC<sub>4</sub> by forming irregular nuclei at the contact. So, irregular nuclei, the nuclei which is formed and it has nuclei -- as the reaction progresses, the nuclei become platelet like.

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**AM OF ALUMINUM MATRIX COMPOSITE**

*mmc → wettability of  
reinforce with matrix*

- **AlSi<sub>10</sub>Mg-SiC Composite**
  - Uniform distribution of plate-like Al<sub>4</sub>SiC<sub>4</sub> structures improves AM composites' mechanical properties.
  - Al's reduced absorption capacity limits laser AM.
  - SiC, a high-energy absorbent, can increase the energy absorption rate and generate enough liquid with continuous melt pools.
  - Increasing the melt pool's energy absorption rate enhances solid-liquid wettability.
  - The particular surface area between Al melt and SiC varies with SiC particle size, affecting composite densification.

*Al → Plasmonic property → try reflect laser.*

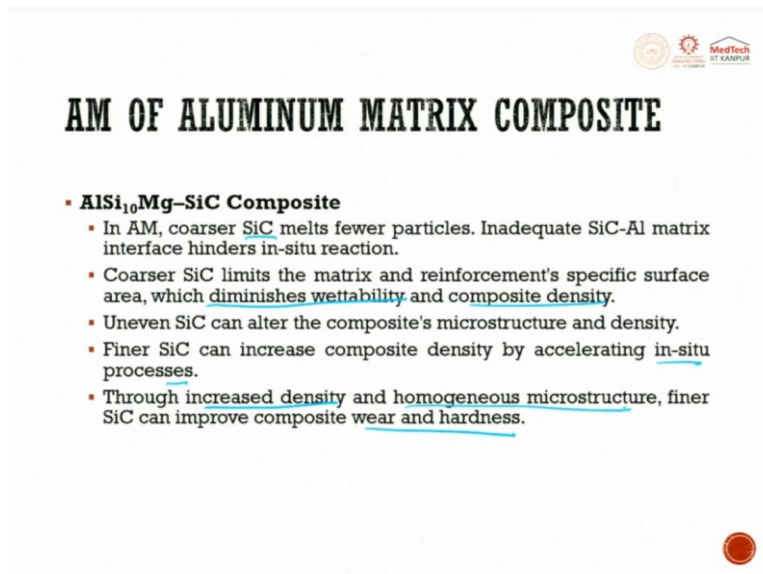
Uniform dispersion of plate like Al<sub>4</sub>SiC<sub>4</sub> structures, improve AM composites mechanical property. Al reduced absorption capacity limits the laser processes. Al reduces absorption, why? Because the Al has a plasmonic property and this plasmonic property whatever it has tries to reflect laser. So that puts an issue with a laser additive manufacturing. SiC an energy observant so, in this SiC absorbs laser in a big way. So, SiC a high energy absorbent can increase the energy absorption rate and generate enough liquid with continuous melt pool. This is very important.

So, Al will try to reflect, but SiC will try to absorb so, now SiC temperature goes high, that in turn tries to transform Al from solid to liquid. Increasing the melt pool's energy absorption rate enhances solid liquid wettability. Solid liquid wettability is also very important. When

we are looking at all these MMC, the wettability of reinforcement with matrix is very important.

If the wettability is not good so, then you will not have interfacial bonds. If the interfacial bond is not there, interfacial strength will not be there. If the strength is not there, then the particulates will get dispersed or it will get dislocated very fast when you try to put it into real time use. The particulate surface area between Al melts and Si varies with SiC particle size affecting the composite densification.

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The slide is titled "AM OF ALUMINUM MATRIX COMPOSITE" in a bold, black, serif font. In the top right corner, there are three logos: a circular one with a gear, a red one with a gear, and a red one with the text "MedTech BY KANPUR". The main content is a bulleted list under the heading "AlSi<sub>10</sub>Mg-SiC Composite". The list contains six items, each starting with a red square bullet. The text in the list is black, with some words underlined in blue. In the bottom right corner, there is a red circular logo.

**AM OF ALUMINUM MATRIX COMPOSITE**

- **AlSi<sub>10</sub>Mg-SiC Composite**
  - In AM, coarser SiC melts fewer particles. Inadequate SiC-Al matrix interface hinders in-situ reaction.
  - Coarser SiC limits the matrix and reinforcement's specific surface area, which diminishes wettability and composite density.
  - Uneven SiC can alter the composite's microstructure and density.
  - Finer SiC can increase composite density by accelerating in-situ processes.
  - Through increased density and homogeneous microstructure, finer SiC can improve composite wear and hardness.

In AM, coarser SiC melts fewer particles. Inadequate SiC-Al matrix interface hinders the in-situ reaction. Coarse SiC limits the matrix and reinforcement specific surface areas which diminishes wettability and composite density. So, diminishes wettability and composite density. Uneven SiC can alter the composite microstructure and density.

Finer SiC can increase composite density by accelerating in situ processes. Though increased density and homogeneous microstructure finer SiC can improve composite wear and hardness, through increase in density. So, through increased density and homogeneous microstructure, finer SiCs can improve the composite structure.



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The slide is titled "AM OF ALUMINUM MATRIX COMPOSITE". It features a list of bullet points under the heading "AlSi<sub>10</sub>Mg-TiC Composite". Handwritten notes in blue ink include "Al<sub>2</sub>O<sub>3</sub>", "SiC", and "TiC" at the top right. A diagram at the bottom left shows a laser beam labeled "Laser power (J/cm²)" hitting a surface. To the right of the diagram, a list of factors is written: "Temp gradient", "Viscosity", "Surface tension", "Capillary force", and "Marangoni flow force". A circular arrow labeled "TiC" indicates the rotation of a particle.

**AM OF ALUMINUM MATRIX COMPOSITE**

**AlSi<sub>10</sub>Mg-TiC Composite**

- During laser processing of AMC reinforced with TiC particles, temperature gradients induce surface tension and Marangoni flow.
- All these actions cause capillary forces on TiC particles, which generate torque. Operating torque spins TiC particles in the melt, redistributing them.
- Temperature gradient affects capillary force concentration.
- Insufficient energy may diminish the temperature gradient and capillary force concentration, resulting in inhomogeneous TiC particle dispersion in the melt.

Handwritten notes: Al<sub>2</sub>O<sub>3</sub>, SiC, TiC

Diagram labels: Laser power (J/cm²), Temp gradient, Viscosity, Surface tension, Capillary force, Marangoni flow force, TiC

Now, AlSi Mg with TiC, we saw with alumina. Then now we are going to see with TiC. We also saw with SiC, the previous one was SiC. During laser processing of additive manufacturing composite reinforcement with TiC particles temperature gradient induced surface tension and Marangoni flow is very important.

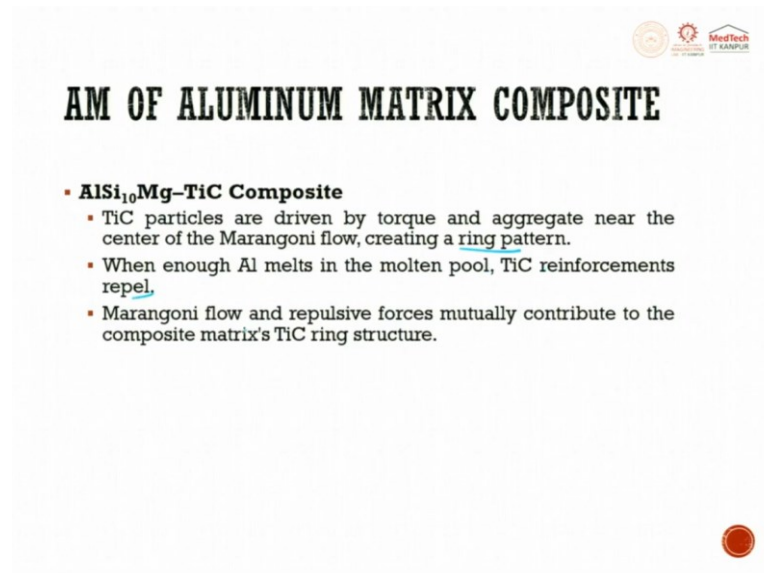
Everywhere it is the same story, temperature induced, surface tension, Marangoni flow is important. All these actions cause capillary force on SiC particles which generates torque. The operating torque spins the SiC particle in the melt and redistributing them. So, TiC particle, this will spin. So, all these actions cause capillary forces on TiC particles, which generate torque.

Operating torque spins the SiC particle. Where is this spinning and all happening? Induced surface tension and Marangoni flow. These two people try to bring in the spin, in the melt and redistribute them. Temperature gradient affects capillary force concentration. So, in variably if you see what they talk about is temperature gradient. Important parameter. Then from there you try to talk about viscosity.

Then we talk about surface tension. Then, we try to talk about capillary force. Then we talk about Marangoni force, flow slash force. So, these are the things which are there. So, temperature gradient affects the capillary force concentration. Insufficient energy may diminish the temperature gradient and capillary force concentration, resulting in inhomogeneous TiC particle dispersion in the melt.

So, insufficient energy means here we are trying to talk about laser power poor, or laser power lean. Lean laser power you use. So, there is an improper or inhomogeneous TiC particle dispersion in the melt.

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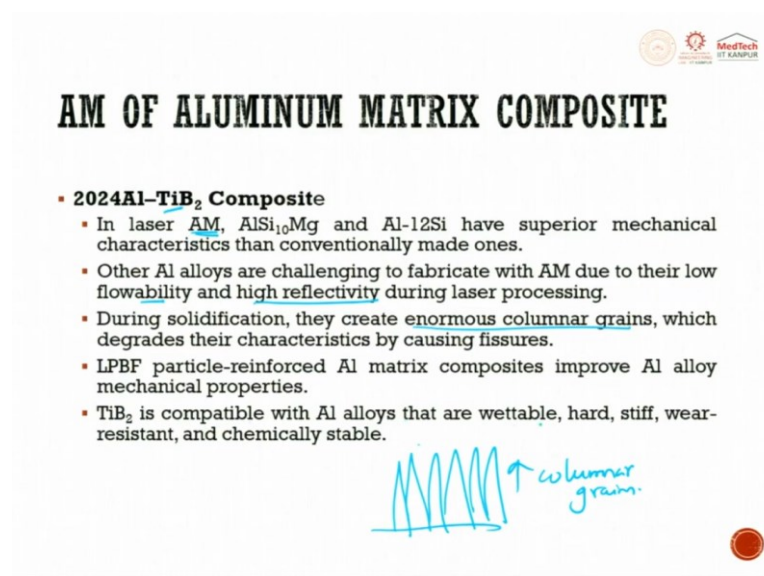


**AM OF ALUMINUM MATRIX COMPOSITE**

- **AlSi<sub>10</sub>Mg-TiC Composite**
  - TiC particles are driven by torque and aggregate near the center of the Marangoni flow, creating a ring pattern.
  - When enough Al melts in the molten pool, TiC reinforcements repel.
  - Marangoni flow and repulsive forces mutually contribute to the composite matrix's TiC ring structure.

TiC particles are driven by torque and aggregate near the center of the Marangoni flow creating a ring pattern. So, this is the same thing when you see, when iron also TiC ring pattern, the same thing. Al melts in the molten pool, TiC reinforcement repels them. Marangoni flow and repulsive forces mutually contributes to the composite matrix TiC ring structure.

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**AM OF ALUMINUM MATRIX COMPOSITE**

- **2024Al-TiB<sub>2</sub> Composite**
  - In laser AM, AlSi<sub>10</sub>Mg and Al-12Si have superior mechanical characteristics than conventionally made ones.
  - Other Al alloys are challenging to fabricate with AM due to their low flowability and high reflectivity during laser processing.
  - During solidification, they create enormous columnar grains, which degrades their characteristics by causing fissures.
  - LPBF particle-reinforced Al matrix composites improve Al alloy mechanical properties.
  - TiB<sub>2</sub> is compatible with Al alloys that are wettable, hard, stiff, wear-resistant, and chemically stable.


*Handwritten diagram showing a series of vertical wavy lines representing columnar grains, with an arrow pointing to them and the text "columnar grains".*



Now, let us look into  $\text{TiB}_2$  composites. In laser, AlSi Mg and AlSi have superior mechanical characteristics than conventionally made ones in laser AM. Other aluminum alloys are challenging to fabricate with AM due to their low flowability and high reflectivity for the laser processing. During solidification, they create enormous columnar grains. What are columnar grains? These are columnar grains, where the heat is dissipated, they create columnar grains. These are columnar grains, which degrades their characteristics by causing fissures.

The laser powder bed fusion particle reinforced aluminum matrix composite improves aluminum alloys mechanical property.  $\text{TiB}_2$  is compatible with aluminum alloys that are wettable, hard, stiff and wear resistant and chemically stable.

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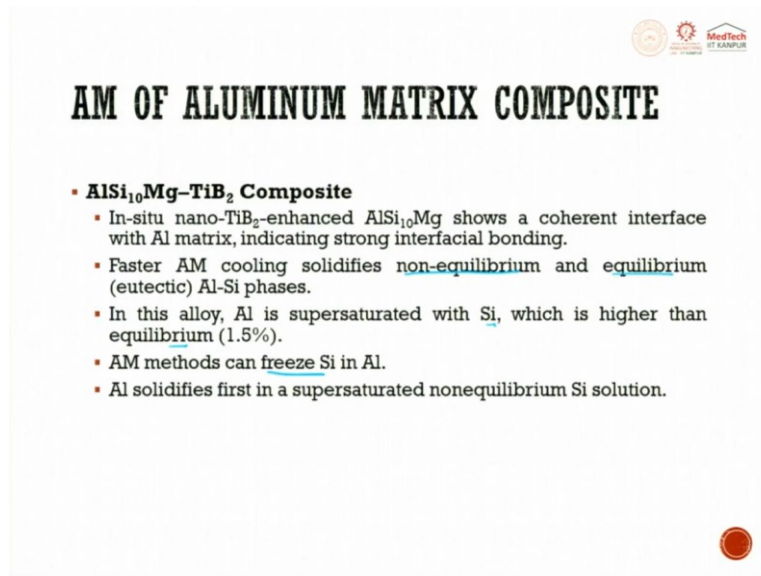
The slide is titled "AM OF ALUMINUM MATRIX COMPOSITE" in a bold, black, serif font. In the top right corner, there are three logos: a circular logo with a gear, a red logo with a gear, and a red logo with the text "MedTech IIT KANPUR". Below the title, there is a handwritten blue arrow pointing to the text "2024Al-TiB<sub>2</sub> Composite" with the note "useful reinforcement" written in blue. The slide contains a bulleted list of points about the 2024Al-TiB<sub>2</sub> composite. The text "fine equiaxed structure" is underlined in blue at the end of the last bullet point. A red circular logo is located in the bottom right corner of the slide.

## AM OF ALUMINUM MATRIX COMPOSITE

- **2024Al-TiB<sub>2</sub> Composite**
  - 2024Al is a high-strength, low-density, heat-treatable aerospace alloy.
  - 2024Al alloy has columnar grains aligned parallel to the construction direction and over many layers.
  - TiB<sub>2</sub> makes columnar 2024Al grains equiaxed.
  - TiB<sub>2</sub> inhibits Al grain development.
  - TiB<sub>2</sub> provides heterogeneous nucleation sites before solidification to promote fine equiaxed structure.

2024 Al is a high strength, low density, heat treatable aerospace alloy. It is two series basically, two series are aluminum alloys have columnar grains, aligned parallel to the construction direction and over many layers, making columnar 2024 aluminum grain equiaxed.  $\text{TiB}_2$  inhibits aluminum grain development,  $\text{TiB}_2$  provides heterogeneous nucleation sites before solidification to promote equiaxed structure. So, this is very useful reinforcement. It tries to create fine equiaxed structures.

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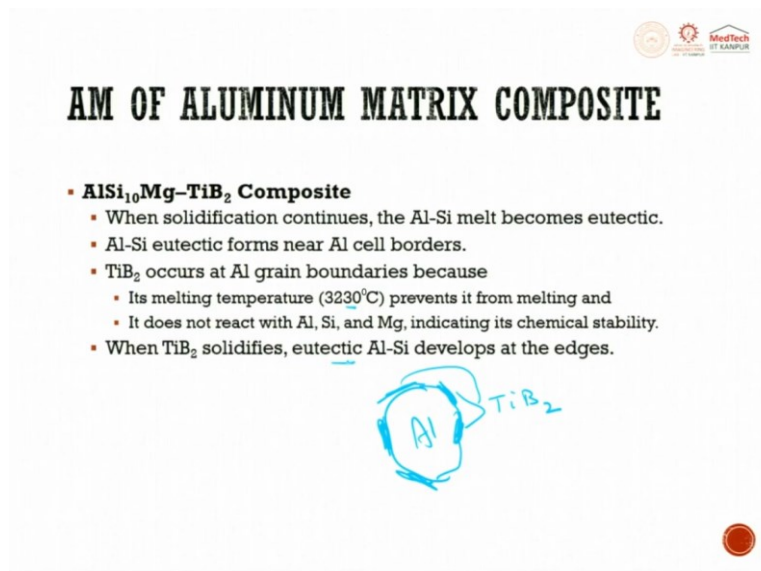


**AM OF ALUMINUM MATRIX COMPOSITE**

- **AlSi<sub>10</sub>Mg-TiB<sub>2</sub> Composite**
  - In-situ nano-TiB<sub>2</sub>-enhanced AlSi<sub>10</sub>Mg shows a coherent interface with Al matrix, indicating strong interfacial bonding.
  - Faster AM cooling solidifies non-equilibrium and equilibrium (eutectic) Al-Si phases.
  - In this alloy, Al is supersaturated with Si, which is higher than equilibrium (1.5%).
  - AM methods can freeze Si in Al.
  - Al solidifies first in a supersaturated nonequilibrium Si solution.


In situ nano TiB<sub>2</sub> enhanced AlSi<sub>10</sub>Mg shows a coherent interface with Al matrix indicating strong interfacial bonds. Faster AM cooling solidifies non-equilibrium and equilibrium Al-Si phases. It is very important to know what is the difference between non-equilibrium and equilibrium Al Si phase. In this alloy, Al is supersaturated with Si, which is higher than the equilibrium of 1.5%. AM method freezes Si in aluminum, Al solidifies first in the supersaturated non-equilibrium Si solution.

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**AM OF ALUMINUM MATRIX COMPOSITE**

- **AlSi<sub>10</sub>Mg-TiB<sub>2</sub> Composite**
  - When solidification continues, the Al-Si melt becomes eutectic.
  - Al-Si eutectic forms near Al cell borders.
  - TiB<sub>2</sub> occurs at Al grain boundaries because
    - Its melting temperature (3230°C) prevents it from melting and
    - It does not react with Al, Si, and Mg, indicating its chemical stability.
  - When TiB<sub>2</sub> solidifies, eutectic Al-Si develops at the edges.



When the solidification continues, the Al-Si melt becomes eutectic. Al-Si eutectic forms near Al cell boundaries. TiB<sub>2</sub> occurs at Al grain boundaries because Al grain boundary you will

have  $\text{TiB}_2$ . This will be Al. All these things are  $\text{TiB}_2$ .  $\text{TiB}_2$  occurs at Al grain boundaries because the melting point is  $3230^\circ\text{C}$  preventing it from melting,  $\text{TiB}_2$  will not melt.

It does not react with Al Si Mg indicating its chemical stability. So, it will be all pushed out. So, once that is pushed out it will be all the grain boundaries. So, all the dislocations will be arrested by the  $\text{TiB}_2$  which is there along the grain boundary. When  $\text{TiB}_2$  solidifies eutectic AlSi develops at the edge.

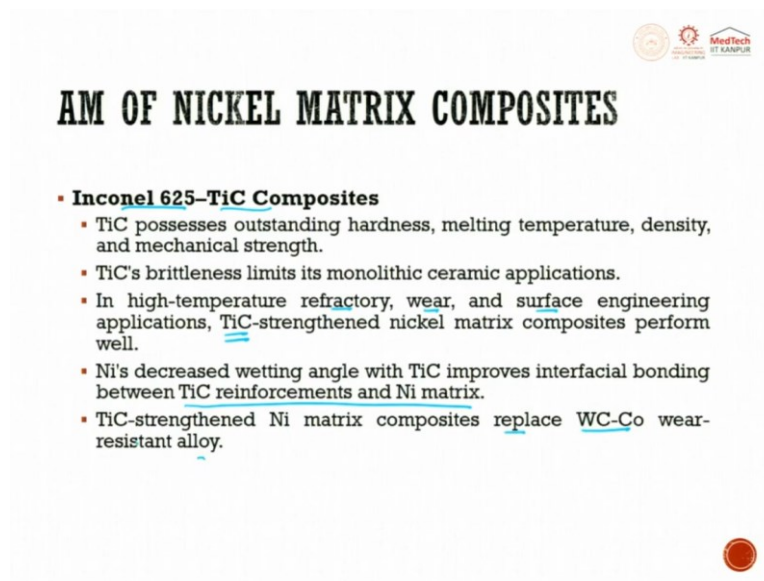
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The slide is titled "AM OF ALUMINUM MATRIX COMPOSITE" in bold black text. In the top right corner, there are three logos: a circular one, a gear-like one, and a red one labeled "MedTech". Below the title, there are handwritten blue notes: "Al 2" and "AA 7" above the bullet point title, and "- laser processing" below the third bullet point. The main content is a bulleted list under the heading "AA7075-TiB<sub>2</sub> Composite".

- **AA7075-TiB<sub>2</sub> Composite**
  - $\text{TiB}_2$ -reinforced AA7075 alloy has an irregular dispersion of reinforcing elements in the matrix.
  - The faster solidification results in nonequilibrium phase transformation and inter-dendritic segregation of solutes.
  - The laser-processed AA7075-TiB<sub>2</sub> composite forms  $\text{Mg}(\text{Zn}, \text{Cu}, \text{Al})_2$  and  $\text{Al}_6(\text{Cu}, \text{Fe})$  intermetallic phases along the grain boundaries and within the grains as well

$\text{TiB}_2$  reinforcement AA7, so earlier we saw two series, Al two series, now we are going to see seven series,  $\text{TiB}_2$  reinforced AA7075 alloy has an irregular dispersion of reinforcement elements in the matrix. The faster solution results in non-equilibrium phase transformation and inter-dendritic segregation of solutes. The laser processing of AA7075  $\text{TiB}_2$  composite forms Mg and  $\text{Al}_6$  intermetallic phase along the grain boundaries and within the grain as well. This is all possible because of laser processing. This is all because of only laser processing, if not also you can get but that is not an energy efficient way.

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The slide is titled "AM OF NICKEL MATRIX COMPOSITES" in a bold, black, serif font. In the top right corner, there are three logos: a circular logo with a gear, a red logo with a gear, and a red logo with the text "MedTech BY KANPUR". The main content is a bulleted list under the heading "Inconel 625-TiC Composites". The list contains five items, each starting with a red square bullet. The text is in a black, sans-serif font. The background is white with a faint grid pattern. A red circular logo is in the bottom right corner.

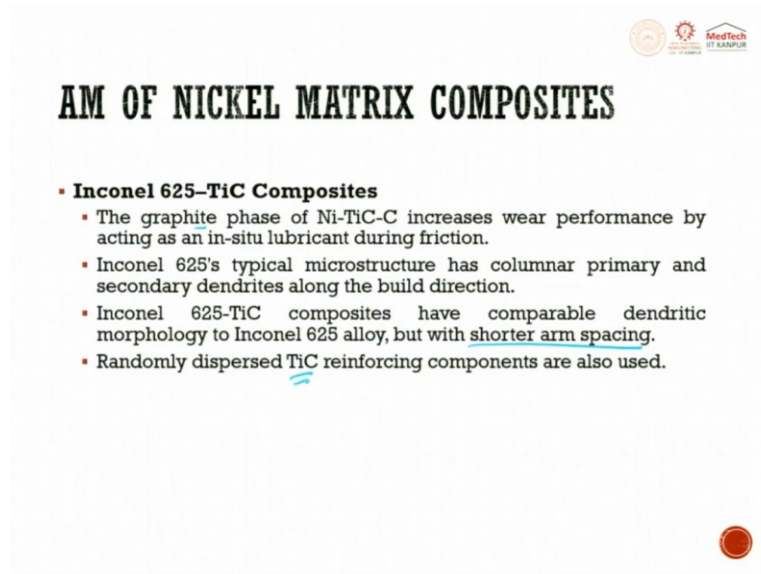
## AM OF NICKEL MATRIX COMPOSITES

- **Inconel 625-TiC Composites**
  - TiC possesses outstanding hardness, melting temperature, density, and mechanical strength.
  - TiC's brittleness limits its monolithic ceramic applications.
  - In high-temperature refractory, wear, and surface engineering applications, TiC-strengthened nickel matrix composites perform well.
  - Ni's decreased wetting angle with TiC improves interfacial bonding between TiC reinforcements and Ni matrix.
  - TiC-strengthened Ni matrix composites replace WC-Co wear-resistant alloy.

Now we will move on to nickel-based alloys. Nickel based alloys are Inconel 625 reinforced with TiC. TiC possesses outstanding hardness, melting temperature, density and mechanical strength. TiCs brittleness, limits its monolithic ceramic application. In high temperature, refractory wear and surface energy applications, TiC strengthened nickel matrix composites perform very well.

TiC performs very well because it tries to give a refractory wear and surface engineering. Ni decreases wettability angle with TiC improves interfacial bonding between TiC with Ni. Ni decreased wetting angle that means to say it can easily spread with TiC improves interfacial bond between TiC reinforcement and Ni matrix. TiC strengthen Ni matrix composite replace tungsten carbide cobalt wear resisting alloys. So, these are very heavy but these are all not very heavy.

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The slide is titled "AM OF NICKEL MATRIX COMPOSITES" in a bold, black, serif font. In the top right corner, there are three logos: a circular one with a gear, a red one with a gear, and a red one with a house. The main content is a bulleted list under the heading "Inconel 625-TiC Composites". The list contains four items, each starting with a red square bullet. The text is in a black, sans-serif font. A red circular logo is in the bottom right corner of the slide area.

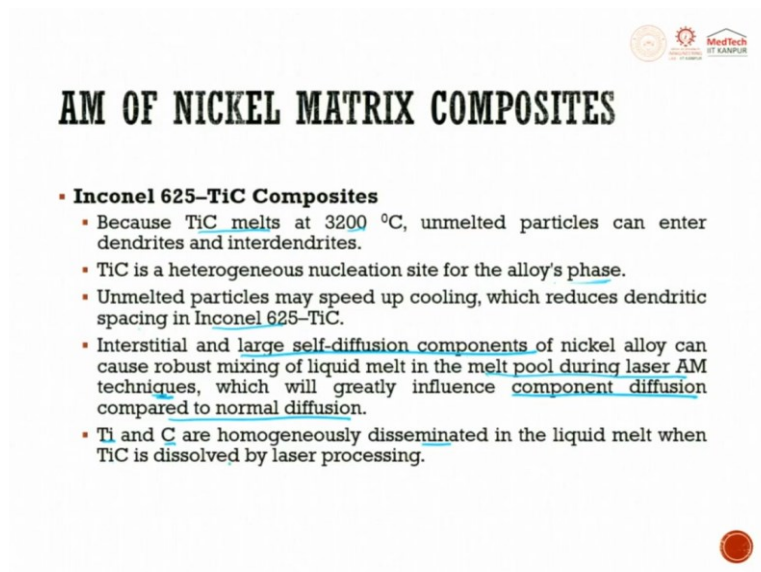
## AM OF NICKEL MATRIX COMPOSITES

- **Inconel 625-TiC Composites**
  - The graphite phase of Ni-TiC-C increases wear performance by acting as an in-situ lubricant during friction.
  - Inconel 625's typical microstructure has columnar primary and secondary dendrites along the build direction.
  - Inconel 625-TiC composites have comparable dendritic morphology to Inconel 625 alloy, but with shorter arm spacing.
  - Randomly dispersed TiC reinforcing components are also used.

The graphite phase of Ni TiC C, we are bringing the C through the graphite phase. Increases wear performance by acting as an insitu lubricating between friction or during friction. Inconel 625's typical microstructure has columnar primary and secondary dendrite along the build direction.

Inconel 625-TiC composites have comparable dendritic morphology to Inconel 625 alloys, but with shorter arm length spacing. Random distribution of TiC reinforcing components are also used today.

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The slide is titled "AM OF NICKEL MATRIX COMPOSITES" in a bold, black, serif font. In the top right corner, there are three logos: a circular one with a gear, a red one with a gear, and a red one with a house. The main content is a bulleted list under the heading "Inconel 625-TiC Composites". The list contains five items, each starting with a red square bullet. The text is in a black, sans-serif font. A red circular logo is in the bottom right corner of the slide area.

## AM OF NICKEL MATRIX COMPOSITES

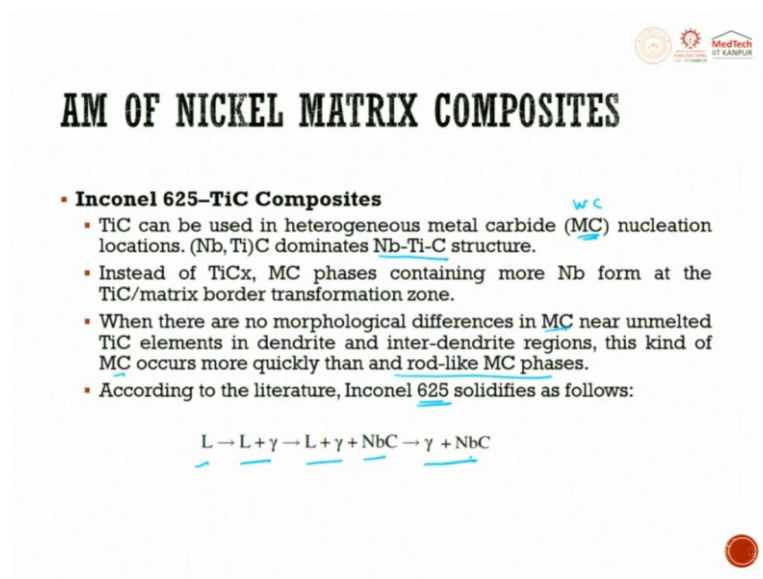
- **Inconel 625-TiC Composites**
  - Because TiC melts at 3200 °C, unmelted particles can enter dendrites and interdendrites.
  - TiC is a heterogeneous nucleation site for the alloy's phase.
  - Unmelted particles may speed up cooling, which reduces dendritic spacing in Inconel 625-TiC.
  - Interstitial and large self-diffusion components of nickel alloy can cause robust mixing of liquid melt in the melt pool during laser AM techniques, which will greatly influence component diffusion compared to normal diffusion.
  - Ti and C are homogeneously disseminated in the liquid melt when TiC is dissolved by laser processing.

Because of TiC melt is around about 3200<sup>0</sup>C unmelt particles can enter dendrites or inter dendrites. TiC is a heterogeneous nucleation site for the alloys phase. Unmelted particles may

speed up cooling, which reduces dendritic spacing in Inconel 625 TiC. Interstitial and large self-diffusion components of nickel alloy can cause robust mixing of liquid metal in the melt pool during laser additive manufacturing techniques, which means greatly influenced the components diffusion as compared to that of normal diffusion.

Melt pool during laser additive manufacturing technique is self diffusion components. Interstitial and self-diffuse components of nickel. Ti and C are homogeneously disseminated in the liquid metal when TiC dissolved by the laser. Ti and C are homogeneously disseminated in the liquid metal when TiC is dissolved by laser power.

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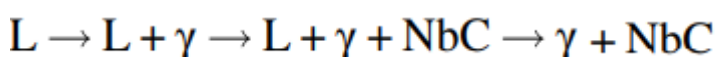
**AM OF NICKEL MATRIX COMPOSITES**

- **Inconel 625–TiC Composites**
  - TiC can be used in heterogeneous metal carbide (MC) nucleation locations. (Nb,Ti)C dominates Nb-Ti-C structure.
  - Instead of  $TiC_x$ , MC phases containing more Nb form at the TiC/matrix border transformation zone.
  - When there are no morphological differences in MC near unmelted TiC elements in dendrite and inter-dendrite regions, this kind of MC occurs more quickly than rod-like MC phases.
  - According to the literature, Inconel 625 solidifies as follows:

$$L \rightarrow L + \gamma \rightarrow L + \gamma + NbC \rightarrow \gamma + NbC$$

When we look at the entire thing TiC can be used in heterogeneous metal carbide, MC that can be WC, TiC, TaC, SiC, nucleation location Nb TiC dominates Nb TiC structure. Instead of  $TiC_x$ , MC phase containing more niobium form at the TiC matrix border transformation zone. When there are no morphological differences in metal carbide, nearly unmelted TiC elements in dendrite and inter dendrite region, this kind of MC occurs most quickly than the rod like structure in this.


From the literature, Inconel 625 solidifies,



So, this is what it is, when the laser is hit, it tries to form structures like this and these are columnar. When you form the composite like this, so you have these  $TiB_2$  forming and they can form structures like this.



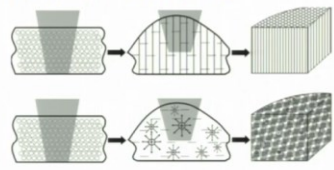
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## AM OF NICKEL MATRIX COMPOSITES

- **Inconel 625–TiC Composites**
  - Because of the partial melting of TiC elements, additional Ti and C particles would be in the liquid melt.
  - In place of developing NbC at inter-dendritic region, MC phases (typically contain Nb, Ti with higher content of Mo) as rod-like morphology precipitate out, then the cooling behavior of the alloy modifies as:  
$$L \rightarrow L + \gamma \rightarrow L + \gamma + MC \rightarrow \gamma + MC \quad (M = Nb, Ti \text{ and } Mo)$$

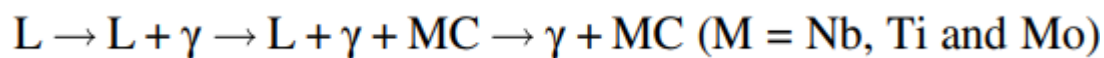
Mechanism of Inconel–TiB<sub>2</sub> composite formation.






Zhang et al. Microhardness and microstructure evolution of TiB<sub>2</sub> reinforced Inconel 625/TiB<sub>2</sub> composite produced by selective laser melting. Opt. Laser Technol. 2016.

Inconel 625 TiC composite, because of the practical partial melting of TiC element, additional Ti and C particles would be in the liquid melt. In place of developing NbC at inter dendritic region, metal carbide phase containing NbTi and higher contents of Mo has rod like morphology precipitates out then the cooling behavior of the alloy is written like this.




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## ASSIGNMENT

- Ni based MMC using AM process  
– Part in real time
- Why AM is alone used for making MMC parts
- EB & LB – its influence on Al matrix composite parts



So, in this chapter, we tried to look out of applications of nickel-based metal matrix composite using additive manufacturing process part in real time. Second thing, why AM is alone used for making MMC parts? Electron beam and laser beam, its influence on aluminum

matrix composite parts. These three questions are very important, that will give you more insight to understand what we discussed till now. Thank you very much.