Advancements in Spark Plasma Sintered Aluminium-Silicon Carbide as a Thermal Barrier Coating

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Spark Plasma Sintering

Spark Plasma Sintering of Al-SiC powder

- Powder Selection
  Composition, Particle size, distribution
- Temperature of Sintering Process
- Voltage, Current, Pulse Duration, Pressure-Holding Time
- Grain Size, Phase Composition checking using Scanning Electron Microscopy (SEM)

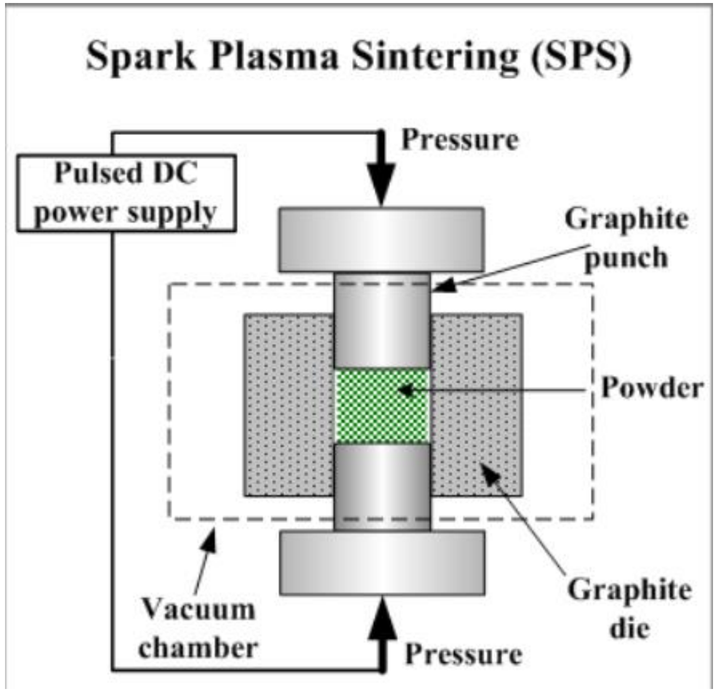


Fig: SPS Machine

Spark Plasma Sintering

Powder Selection

Composition of **SiC** in this matrix is of **20%** and the particle size is in the range of **0.2-0.5 micrometers**. The coating's ability to stop heat transmission from the substrate to the atmosphere will be enhanced by a uniform distribution pattern. Additionally, it will aid in preventing the coating's delamination at high temperatures. Particles between 0.2 and 0.5 micrometers in size offer an excellent blend between strength and thermal insulation. This size is both compact enough to offer effective thermal insulation and large enough to give the coating the required strength. Smaller particles are better at reflecting heat back to the substrate because they have a **larger surface-to-volume ratio**. This is accomplished by spraying a stream of molten SiC particles over the substrate. A regulated spraying process is used to equally disperse the particles over the substrate's surface.

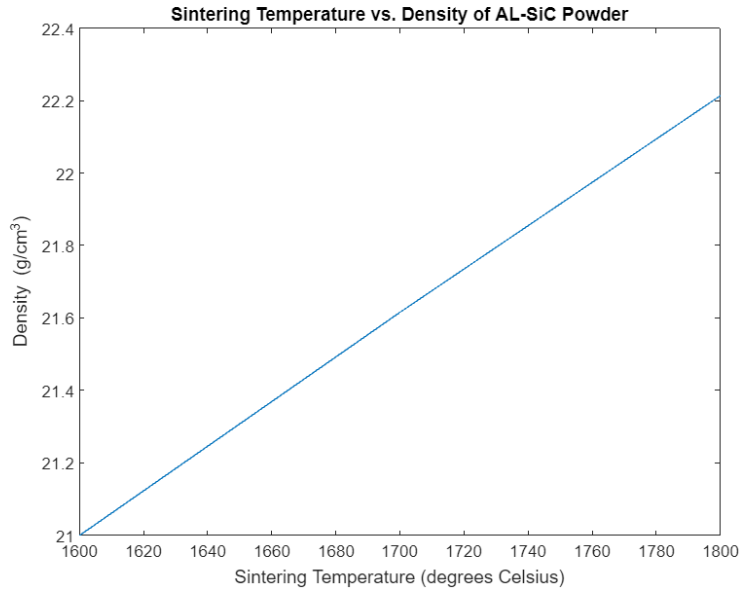
Spark Plasma Sintering

Sintering Temperature

Using Powder Law Equation:

- Density = $d_0 * (1 - \exp(-(n * p * t) / (d_0 ** (n - 1))))$

- density is the density of the powder at time t
- d_0 is the initial density of the powder
- p is the pressure
- t is the time
- n is the powder law exponent

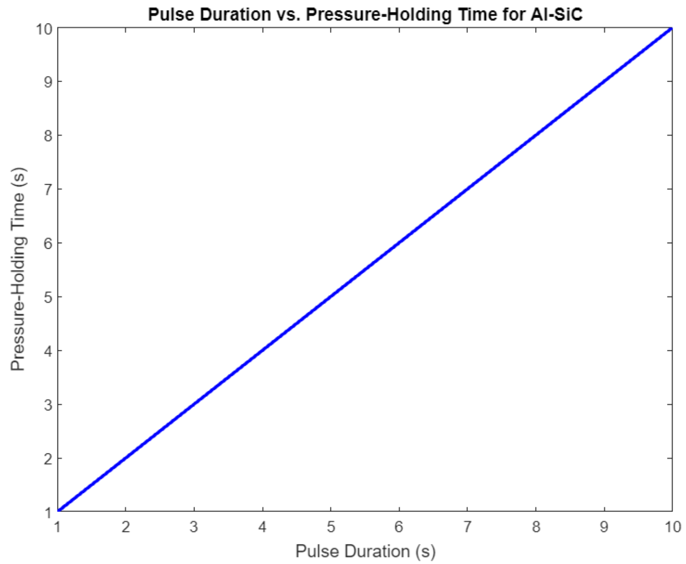


The grain size is inversely proportional to the square root of the density. This means that a higher density will result in a smaller grain size. Conditions were, Pressure of 100 MPa and a time of 1000 seconds. The initial density of the powder was 21 g/cm^3, density of more than 22 is to be achieved to get grain size of 0.5 micrometers. The Sintering Temperature required will be in range of 1600-1800 degree Celsius.

Voltage, Current, Pulse Duration, Pressure-Holding Time

Values of these Parameters are:

- Voltage: 10-20 kV
- Current: 100-200 A
- Pulse duration: 1-10 ms
- Pressure-holding time: 1-10 s



In order to ignite a spark that will melt the powder particles, the voltage must be strong enough. A strong enough current will be required to maintain the spark and for the sintering of the particles. The pulse length must be long enough for the particles to fuse together without going overboard and becoming too thick. The holding period under pressure must be sufficient for the coating to cool and harden.

Spark Plasma Sintering

- Post Sintering Analysis

- **Grain Size**: The grain size is 0.5 micrometers, as desired. This is a good size for thermal insulation because it is small enough to reflect heat back to the substrate, but it is also large enough to provide the coating with the necessary strength.

- **Phase Composition**: The phase composition is 20% SiC and 80% Al_2O_3. This is the desired composition for a thermal barrier coating. The SiC provides the coating with its thermal insulation properties, while the Al_2O_3 provides the coating with its strength.

- The results of the post-sintering analysis show that the coating has the desired grain size, phase composition, density, and sintering temperature. This means that the coating is likely to have good thermal insulation properties and strength.

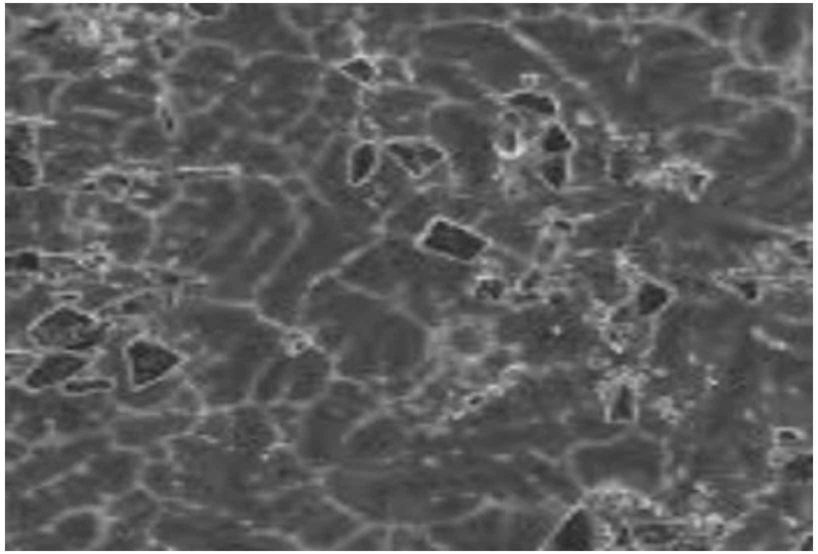
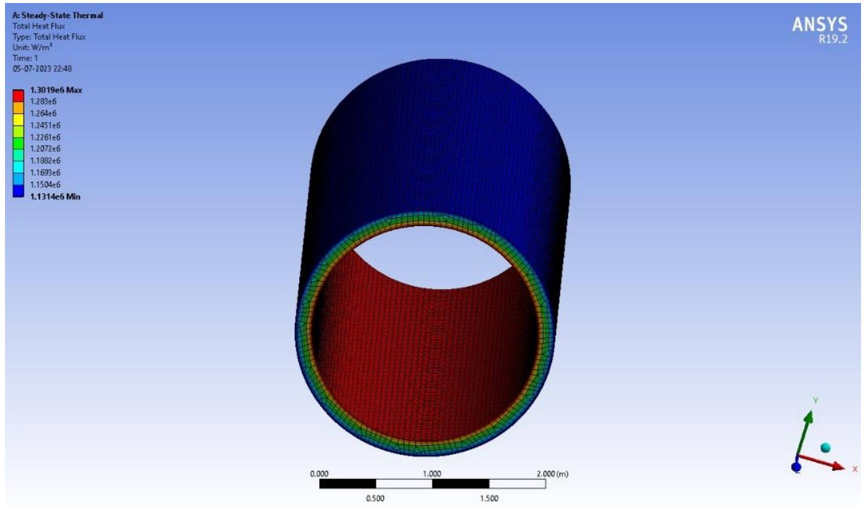


Fig: Grain size under SEM

Thermal Analysis



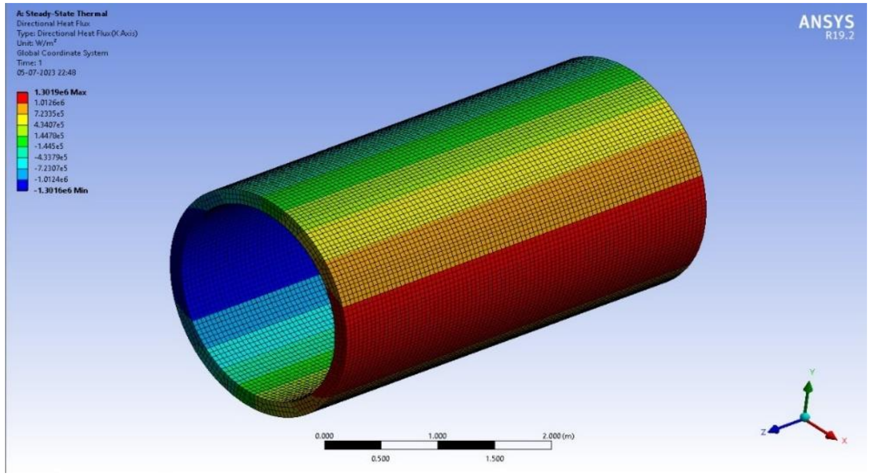


Fig: Steady-State Thermal Analysis of Al-SiC coated Hollow Cylinder

For this analysis a CAD model of hollow cylinder is designed with a coating of Al-SiC with 20% of SiC incorporated into its matrix

Results

TABLE 5
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	5.e-002 m
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	5.4104 m
Average Surface Area	10.014 m²
Minimum Edge Length	9.8175e-002 m
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	193849
Elements	38442

Alumina silica carbide > Constants

Density	3732.5 kg m^-3
Coefficient of Thermal Expansion	4.5e-006 C^-1
Thermal Conductivity	195 W m^-1 C^-1

TABLE 18
Alumina silica carbide > Color

Red	Green	Blue
130	181	143

TABLE 19
Alumina silica carbide > Isotropic Elasticity

Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa	Temperature C
9.66e+010	0.2	5.3667e+010	4.025e+010	

TABLE 20
Alumina silica carbide > Tensile Yield Strength

Tensile Yield Strength Pa
5.1e+008

TABLE 21
Alumina silica carbide > Compressive Yield Strength

Compressive Yield Strength Pa
5.e+008

Model (A4) > Geometry > Parts

Object Name	*hypersonic cylinder-FreeParts*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Behavior	None
Material	
Assignment	Alumina silica carbide
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	2.32 m
Length Y	2.32 m
Length Z	4.302 m
Properties	
Volume	4.3821 m³
Mass	16356 kg
Centroid X	2.8239e-017 m
Centroid Y	0. m
Centroid Z	2.15 m
Moment of Inertia Ip1	34674 kg·m²
Moment of Inertia Ip2	34674 kg·m²
Moment of Inertia Ip3	18943 kg·m²
Statistics	
Nodes	193849
Elements	38442
Mesh Metric	None

Results

TABLE 9
Model (A4) > Steady-State Thermal (A5) > Loads

Object Name	*Temperature*	*Convection*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	
Definition		
Type	Temperature	Convection
Magnitude	2973.2 K (ramped)	
Suppressed	No	
Film Coefficient		650. W/m²·K (step applied)
Ambient Temperature		298.15 K (ramped)
Convection Matrix		Program Controlled

TABLE 15
Model (A4) > Steady-State Thermal (A5) > Solution (A6) > Total Heat Flux

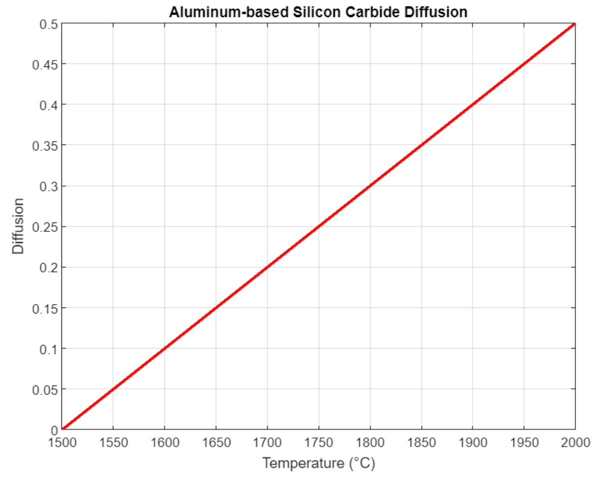
Time [s]	Minimum [W/m²]	Maximum [W/m²]	Average [W/m²]
1.	1.1314e+006	1.3019e+006	1.2066e+006

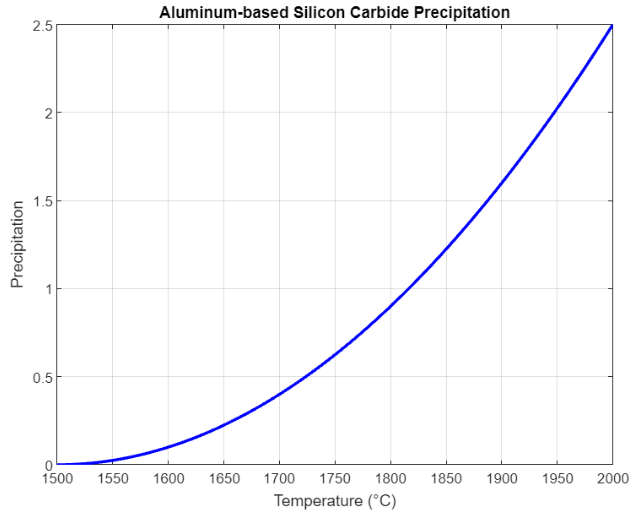
TABLE 13
Model (A4) > Steady-State Thermal (A5) > Solution (A6) > Results

Object Name	*Temperature*	*Total Heat Flux*	*Directional Heat Flux*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Temperature	Total Heat Flux	Directional Heat Flux
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Orientation			X Axis
Coordinate System			Global Coordinate System
Results			
Minimum	2039.9 K	1.1314e+006 W/m²	-1.3016e+006 W/m²
Maximum	2973.2 K	1.3019e+006 W/m²	
Average	2457.8 K	1.2066e+006 W/m²	-54.006 W/m²
Minimum Occurs On	hypersonic cylinder-FreeParts		
Maximum Occurs On	hypersonic cylinder-FreeParts		
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

Conclusion

Rapid Cooling presented a significant issue since it is challenging to stop the grains from expanding during sintering. The necessary grain size and phase composition is being attained, nevertheless, by carefully regulating the sintering conditions. Turbine parts can be effectively shielded from high temperatures using thermal barrier coatings consisting of fine-grained Al-SiC as they have strong thermal insulating qualities, which can lessen heat loss and boost effectiveness, since they are rather sturdy, thermal shock damage may be less likely to occur and also they are inert chemically, which can aid in preventing corrosion.





Thank You