Effectiveness of Char over Ablative Materials- A Review

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Abstract: -

At the Hypersonic Speeds during Re-entry of a vehicle it experiences Severe Aerodynamic Heating over the surface.it is important to choose the material which have the capability to resists high heating temperatures. For this purpose, Thermal Protective Systems (TPS) are Developed. TPS is the Barrier that protects the body or vehicle during reentry. The material which we are choosing for atmospheric exposed surface area should have high reluctance to Heat and these materials are termed as Ablative Materials. These ablative materials protect the Structure, aerodynamic surfaces and payload of vehicles from heat and damages also helps in cooling the combustion chamber of Rocket engines. Formation of Char over the surface is a criterion of Ablative Material to be chosen. Char is a carbonaceous deposition; Formation of Char over the surface does not allow heat transfer to inside materials. Ablative material must be chosen based on following criteria (i). Resistance to thermal heat. (ii) High char forming capacity (iii) low coefficient of thermal expansion. In order to choose an Ablative Material for the above-mentioned conditions a review had been done.

Introduction: -

Ablation is eroding or removing of the material. Ablative materials show resistance towards ablation. There are melting and Non-melting type of ablative materials which are thermoplastic and thermosetting respectively. As of High char forming capability and efficient thermal protection, we prefer Non-melting type than melting type Ablative Materials. Most TPS materials are reinforced composites where Organic resins, composites, Polymers, nanocomponents are used as Ablative Materials due to their low thermal conductivity. Resins which are used in Ablative material as Reinforcement decomposes when they exposed to high temperatures and their decomposition leads to formation of carbonaceous deposit called as “Char” and forms Boundary layer over the surface. Due to the formation of char and Boundary layer resist the allowance of heat inside and energy has been transferred from re-entry vehicle to Atmosphere. The following Diagram shows the phases that an Ablative material undergoes. i.re-radiation from outer surface to atmosphere, ii. Decomposition of outer layer iii. Mechanical ablation Resistance.

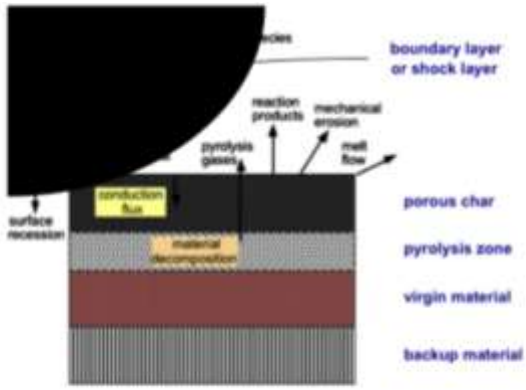

Figure 1: combination of ablative material[1]

This review on ablative material done to choose the best material for re-entry vehicle at hypersonic regimes to protect the body from high temperature and pressure. Different composition of reinforcement of different materials shows a greater variation of thermal resistance and stability of the material. Thermomechanical analysis (TMA), Thermogravimetric analysis (TGA), Oxyacetylene test are conducted to ablative materials to test their Thermal stability, mass of material with respect to temperature, char forming capacity, thermal conductivity and rate of erosion.

G.Pulci [1] in this paper Experimental work has carried on two materials i. Resole resin mixed with Graphite ii. Resole resins coupled with Graphite foam we used Reinforcement Material Graphite Foam which is open-cell, rigid carbon based material and Rigid Graphite felt(Sigrathem rigid felt) which is retentive insulating material made of graphite fibers and a carbon binder And Matrix-A resole phenolic resin to develop and improvement Mechanical Resistance and insulation Performance. Phenolic resin has high Oxidation Resistance as well heat of ablation among all thermosetting resins which is a non-melting ablative material.

- Experimental Results shows that Hardness on the resins surfaces is higher than on cross-sections. Modulus of Elasticity of both Grafoam carbon foam and rigid felt is high.

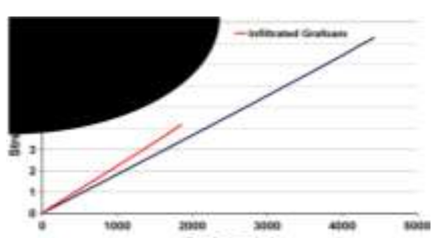

Figure 2: Stress–strain curves registered during four-point bending tests of infiltrated Sigratherm and Grafoam.[1]

- Composite stiffness of resins is high,Foam exhibited low thermal Conductivity at high temparatures.Felt exhibits low thermal conductivity at low temparatures.

- Foam exhibits lower thermal shock resistance where as rigid graphite felt high fracture toughness.
- Finally it has concluded that Graphite rigid felt is the best for re-entry condition as it has low thermal conductivity as well as high char capacity.
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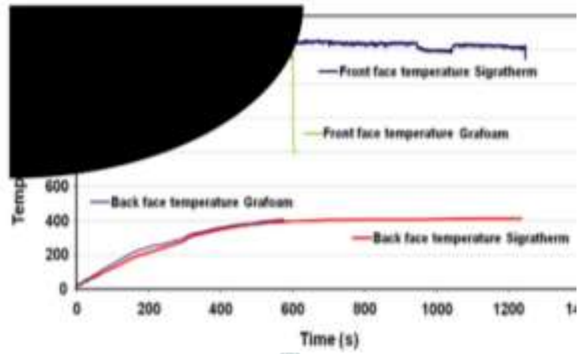

Figure 3: Front face (from pyrometer) and back face (from thermo-couple) temperatures of Sigratherm and Grafoam composites during oxyacetylene exposure test.[1]

Maurizio Natali [2] says that Powder Novolac Resin; CB-carbon black; MWNT- Multi-walled carbon Nano tubes;PR-CB:-50% weight PR&50%weight CB;

- in this research paper the author investigated the ablative properties on Carbon nano-filler composites in two different materials of Reinforcement i. Carbon black ii. Multi-walled carbon Nano tubes [MWNT], which are used to produce Phenolic Composites.Reinforced polymers gives the best results towards Heat shielding whereas matrix are weak after Burning.PR-CB and PR-MWNT have higher weight loss also evaluation of less carbon monoxide and carbon di oxide compared to unreinforced or pure PR. Moreover PR-CB and PR-MWNT has less Voltization in Decomposition of matter and low volume shrinkage when exposed to hypersonic regimes.
- Temperature profile of these ablative materials shows a dramatic variation which impacts their Ablative performance. PR-MWNT nano filler material shows a faster increase compared to PR-CB composite and the C_p value of this nano-filler have higher values.
- Thermal diffusivity and Thermal Conductivity of PR-MWNT is higher than PR-CB. The following diagram shows Temperature profile

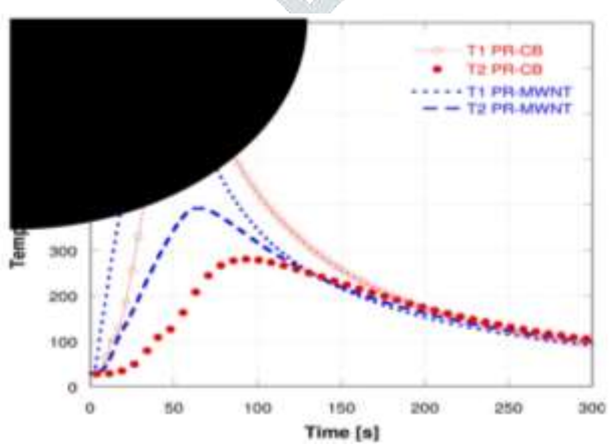

Figure 4: Temperature profile [2]

- From this paper the investigation over these carbon black and nano-filler reinforcement of novalac resins shows increase in Dimensional stability, also PR-CB and PR-MWNT had superior thermal stability
- PR-MWNT has greater Erosion rate, thermal diffusivity and less Char production when exposed to higher temperatures comparing to PR-CB. Where as PR-CB produces a thick charred layer over the surface when exposes to high temperatures which helps to protect the Virgin material.
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Ahmad Reza Bahramian [3] Kaolinite is – Aluminosilicate: DMSO- Dimethyl sulfoxide: in this paper comparison between natural kaolinite(phenolic/asbestos-kaolinite) and modified kaolinite (kaolinite DMSO complex-Nano composites different compositions).NKA1,NKA2,NKA3- are modified Nano composites or reinforced ones.

Table 1: The following Composition and characteristics of Nano Composites

Sample	Component	m_{clay}/m_{resin}	W_{resin}	W_{clay}	$W_{asbestos}$
Composite	Asbestos cloth/phenolic resin composite	0.00	0.50	0.00	0.50
NKA1	Asbestos cloth/phenolic resin/kaolinite nanocomposite	0.06	0.47	0.03	0.50
NKA2	Asbestos cloth/phenolic resin/kaolinite nanocomposite	0.10	0.44	0.04	0.52
NKA3	Asbestos cloth/phenolic resin/kaolinite nanocomposite	0.14	0.42	0.06	0.52

- Modified kaolinite (Nano composites) has loss of weight with the increase in temperature and Thermal decomposition of Nano composites towards temperature is high when compared to Phenolic/asbestos composite
- Temperature Distribution over the back surfaces of these nano composites effects the ablative performance.

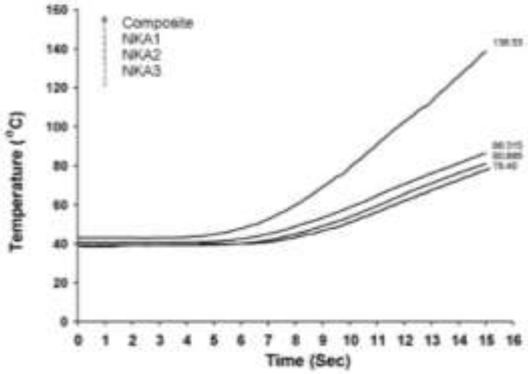

Figure 5: Temperature distribution at back surface of NKA1, NKA2, NKA3 in comparison with natural composites (phenolic/asbestos composites)[3].

- Thermal Behavior of nano composites shown in Flame test among all modified nano composites NKA3 Nano composite shows lower heat release rate and lower mass loss or weight loss at higher temperature which means higher insulation and lower thermal conductivity.

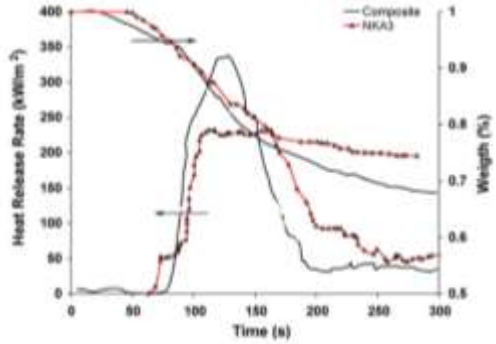

Figure 6: Thermal behavior of Nano composites and natural composites [3]

- The above result shows that NKA3 Nanocomposites responds less deformation of mass when exposes to temperature which helps to protect material from hypersonic regimes.
- NKA3 Nano composite shows lower heat release rate and lower mass loss or weight loss at higher temperature which means higher insulation and lower thermal conductivity.
- And the final investigation of these experimental results concludes that:-

i. Polymer layered silicate composites results high thermal stability

ii. NKA3 Nano composite shows lower heat release rate and lower mass loss or weight loss at higher temperature which means higher insulation and lower thermal conductivity.

iii. Ablation performance (char forming capacity) of NKA3 Nano composite is higher than asbestos cloth/phenolic composites

NKA3 Nano composite is suitable for atmospheric re-entry conditions.

CONCLUSION: -

From the review of ablative materials concludes that it is important to choose a material for Ablation resistance which has the capability to protect the surface from severe Aerodynamic heating as well as Shocks during atmospheric re-entry. Char which is carbonaceous layer which forms over the surface helps to not allowing heat inside the material. The above review shown that Carbon content in the material matters the most while choosing an ablative material as in G.Pulci[1] shows that the importance of carbon content in the formation of char so, the material should be chosen as of carbon content. Thermal Conductivity and thermal diffusivity which are considered as another factor of best Ablative material the material which has low thermal conductivity does not allow heat to pass through it so our material will be free from damage at higher temperatures. Maurizio Natali [2] shows another factor which is variation of mass reduction of material when exposes to higher temperature the lower the mass reduction of the material the greater the resistance towards the heat. Ahmad Reza Bahramian [3] gives the ablation performance of nanocomposites and their effect over the material formation of residue over the surface as well as thermal expansion of the material are also considerable parameters for a best ablative material. The material with low thermal expansion, thick char layer over the surface, low thermal diffusivity and conductivity, low mass reduction to high temperatures and good mechanical properties are to be chosen as best Ablative Materials.

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