Wave-absorbing Structural Ceramic Matrix Composites

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Abstract: with the rapid development of radar detection technology, materials with wave-absorbing and load-bearing perform Ance are needed in order to satisfy the stealth requirements of aerospace vehicle key thermal. It is thus necessary to develop the high-temperature wave-absorbing structural. In this paper, the Wave-absorbing matching principles (impedance matching and attenuation principles) and mechanical match ing principles (elastic modulus matching,interfacial debonding and Thermal expansion coefficient matching principles) of the wave-absorbing structural composites were introduced. Recent development of the High-temperature wave-absorbing structural ceramic matrix composites was reviewed. In addition, the development trend of designing absorbing structural materials with excellent properties according to the Wave-absorbing and mechanical matching principles was also prospected.

Keywords: wave-absorbing, mechanical properties; ceramic, composites; high temperature

The absorbing material refers to the effective absorption of incident electromagnetic waves , and the Power Magnetic Energy converted to heat or other forms of energy dissipation (loss type), or can cause electromagnetic interference to disappear (interference), To significantly weaken the A class of electromagnetic function materials for echo intensity [1-2] . ideal wave absorbing material should have thickness ( ) , mass light , absorption band width , absorptive capacity strong features , and its chemical composition and structure are stable [3]. root different dissipation mechanism , the absorbing material can be divided into electrical loss type (as Carbon system material ,conductive polymers , ZnO,SiC etc) and magneto-lossy (like Iron oxygen body , carbonyl iron , superfine Metal powder, etc.). electric lossy absorbing materials generally low density , Good mechanical properties , benefits such as high temperature , but

Has a poor wave-absorbing performance , The has a narrower absorbing band ; Magnetic Loss-absorbing material material generally has good absorbing performance , filter bandwidth and so on benefits , but its density Greater , High temperature stability poor [4] . to meet air space flight High Temperature parts stealth requirements , absorbing materials should have a high temperature tolerance , anti-oxidation , Good mechanics performance [5] . so , Comprehensive consider suction synergy between wave performance and mechanical properties , continuous SiC Fiber Strong ceramics matrix composites are very latent in the integration of high temperature absorbing structuresForce [6 []]. from material design angle , Wave-absorbing structural ceramic base Composite materials need to meet both wave-absorbing and mechanical properties Theprinciple of "" .

1. Wave-absorbing performance matching principle

Electromagnetic waves are identical and perpendicular to each other by an electric field and a magnetic field in space derivative emitted shock particle wave , with wave particle duality . when electricity magnetic wave from one medium to another media ((as from air into solid body material) when , reflection , phenomena such as absorption and transmission . so , Materials with excellent absorbing properties should make the electromagnetic wave as much as possible into material internal , Reduce reflection section , to meet impedance match original then ; and absorbing as much electromagnetic waves as possible , reduce transmission section , the satisfies the absorption attenuation principle .

1.1 Impedance matching principle

to get the electromagnetic wave as much as possible into the inside of the material , Material Table face to free space (air) impedance match . based on transmission line theory , Reflection coefficient of flat material in free space r vs equivalent Impedance Z_m The has the following relationship :

where : Z0 , ¡î 0 and E0 is the impedance of the free space , permeability and Dielectric constant ;Z_m ,, and er respectively for impedance of material , relative to complex magnetic conductivity and relative complex permittivity , when material is non-magnetic , its relative complex permeability to 1- 0. Microwave absorbing material in an ideal state response to electromagnetic waves No reflection (r=0), to meet $Z0=Z_m$ conditions for . But it's almost impossible to implement in the reality. can only try to get the impedance of the material surface close to empty gas impedance , to achieve minimal reflection of electromagnetic waves . so the relative complex dielectric constant of the surface material is lower when the design materials , do may approach the relative complex permittivity of air (1 -0.

1.2 Attenuation principle

interacts with the material when electromagnetic waves enter the material , material for loss of electromagnetic wave , need to meet attenuation principle , quickly and as much loss and attenuation of electromagnetic waves , reduce transmission Section . to analyze material from angle of conductivity loss and polarization loss to absorption of electromagnetic waves .

1) conductivity loss : Assuming no polarization relaxation , That is, no pole loss of time , dielectric loss completely caused by leakage . based on Maxwell electromagnetic theory , for frequency ®, field intensity is £ electromagnetic wave , The energy density that the absorbs from the material P is

$P = As_0 s '' \backslash E \backslash^2$ (4)

so , the conductivity loss of a material can be made with complex dielectric constant imaginary part e ''

represents A .

2) polarization loss : Assuming material leakage conductivity 0 = 0 , is the material The loss of electromagnetic waves comes entirely from dielectric polarization , at this time the energy density that the material absorbs for the user is

$P = RNs_0 s ' | £ |^2$ (5)

so , The polarization loss of the material can be used with complex permittivity real parts e ' to represents .

Design Material , for the electromagnetic waves that are emitted into the material to be maximum absorption , require internal material to have a larger complexdielectric constant . but , High complex permittivity may cause material's The impedance does not match the impedance of free space . so that the material has a better electromagnetic wave absorbing performance , The takes account of the impedance matching and attenuation principle . Duan etc [7] and xue etc [8] respectively, the 2. mmThick material on X band (8. 2 ~ 12.4 GHz) Electromagnetic reflection coefficient RC is less than -10 dB (greater than % % Electromagnetic waves are absorbed) when ,Different electromagnetic frequencies The range of complex permittivity corresponding to the rate of and ten GHz with different dielectric Valid absorption bandwidth for constants , As shown in figure 1 shows . Yin etc [9] the summarizes microwave absorbing materials in X The band should have a medium dielectric constant Real and imaginary parts , e ' should be greater than 5 and less than , e is greater than 1 and less than ten. Lower and higher permittivity and dielectric loss will make the material The materials are respectively presented with electromagnetic transmittance and electromagnetic shielding characteristics .

1.3 design of wave absorbing composites

The optimization design of the absorbing composite materials mainly includes the macroscopic design and

Structure unit microstructure design . on the macro ,composite material material can be designed as a single-layer absorbing material , Double-layer absorbing material and multi-layer suction
-Matched absorber [a] (Chart 2c), Jaumann type absorber [[](equivalent to multiple Salisbury screen absorber overlay) etc multi-layer absorbing material , the pass Change the effective impedance along the thickness direction to improve the wave absorption of the material performance .

wave material . for single-layer absorbing materials , like Dahlenbach absorption on the microscopic , The high response of composite to electromagnetic waves by

Body [ten] (Chart 2a), to achieve interference-absorbing effects , thickness of material depends on the microstructure of the material . to make the composite material that is designed to have the

^ and the wavelength of the incident electromagnetic wave 2, the relative complex permittivity of the material & The following relationships should be satisfied outside and relative complex permeability [one] :

N and 1 ^{4}

where : N is odd . Once the thickness of the material is fixed , its absorption The frequency of electromagnetic waves is also fixed , thus single-layer absorbing material withfeatures such as narrow absorption bands . to meet the actual application of the broadband suction of the requirements , can take the Salisbury Screen Absorber [a] (Chart2b), impedance horse
wave absorbing function , The microstructure of should benefit the impedance matching principle and implementation of the attenuation principle , that is, the dielectric constant of fibers and substrates should be Reasonable match . Yin etc [9] the summarizes the canon of fiber-reinforced composites Wave-absorbing microstructure model ,**Figure 3** shows . through low dielectric constant number of wave material or stomata (an phase), Electrical loss of high dielectric constant material (B phase) and medium dielectric constant material (C phase "") design material ¡î and , to optimize the absorption of dielectric composites Wave performance .

2. Mechanics Performance Matching principle

Fiber toughened ceramic matrix composites (CMC) The fiber in the is the primary to host units , and toughening the matrix ; its toughening machine The implementation of the system depends on fiber / base reasonable Match . from mechanical properties angle , fibers and substrates should match elastic modulus matching , interface debonding

and thermal expansion coefficient matching requirements .

2.1 modulus of elasticity match

assumes that fiber-toughened ceramic matrix composites are subjected to a force-deformation process ,, consistent deformation of fibers and matrices , and fiber fracture strain above matrix break strain , can be based on (7) Composites in strength of matrix fracture %

(h/a) less than 0.25 when, a crack through the interface must be biased option thermal expansion coefficient close to and slightly smaller than the fiber matrix , makes the fiber

spin and interface debonding . Primary hosting .

3. Wave-absorbing structural ceramic matrix composites

Fiber toughened ceramic matrix composites basic composition unit for fiber Victoria , Matrix and Interface . based on the wave-absorbing performance matching principle , recoverable with medium dielectric constant and medium dielectric loss SiC all fibres with low dielectric low loss Si_3N_4,BN, SiC etc Matrix ; or Low , dielectric constant and low dielectric loss SiC, Si 0 2, Al2 0 3 , Si 3 N 4 , BN The loss of the fibers in conjunction with the intermediary SiC , sibc , SiCN , SIBCN equal-base system for absorbing wave-structured composites . View pre-temperature absorbing structure ceramic matrix composites mainly connected continue SiC fiber toughened ceramic matrix composites main .

3.1 SiC Fiber

precursor conversion to a SiC ceramic fibers are currently SiC The mainstream of fiber research and development , Foreign commercial fibre grades and manufacturing plantsThe home is predominantly : Nicalon (Nippon Carbon) , Tyranno (Ube Industries) and sylramic (Dow Corning) , and so on ; is in the

The main fiber in the research and development phase of IS Xiamen University's amosic Fiber , University of Defense technology KD fiber and Suzhou Sai Lifi SLF Fiber .

Table 1 and Table 2 for several foreign products SiC Fiber and domestic kd-sic fiber , SLF Fiber Basic performance [19-25]. According to the amount of oxygen containingthe precursor conversion method is generally prepared by the SiC fiber is divided into 3 Generation . I generation and II on behalf amorphous si-c-o fiber , its oxygenatedwith high , Low production cost , high intensity , break strain big , and low modulus , But poor thermal stability . III on behalf of high crystallinity , Near Stoichiometric SiCfiber , Low oxygen content , break strain small , High modulus , production cost High , But thermal stability is good . to further improve SiC Fiber thermal stability sex , and achieve the purpose of adjusting its resistivity , typically mixes in the pioneer body Miscellaneous Ti, N , Zr , Al , B Elements [26-29] . The fiber is generally not only used as a toughening phase in a wave-absorbing structure , also acts as a suction Wave agent . diagram 5 for the different models reported in the current literature SiC Fiber dielectric performance , absorbing wave performance and mechanical properties [+, 30-34] .

3.2 Ceramic Matrix

Wave-absorbing structural ceramic matrix composites are commonly used in substrates with C,SiC, AI2O3 ,Si 0 2 etc , where:SiC The matrix is compared to

C The substrate Dielectric property is tunable and good , and the mechanics of the oxide matrix performance and high temperature performance , Spotlight on . SiC generic impurity half conductor , is the main component of Multi-Band high-temperature absorbing material [35-38] . But normal method preparation SiC absorption less efficient , must be improved by increasing the SiC

Purity and element doping (B,A1 etc III family element or N and P , and so on V Family Element) and so on [3941] work with , to adjust its conductivity and electromagnetic performance .

diagram 6a is Liquan [%] The doped summary SiC Dielectric of can be . recent , Excellent performance SiCN [+],SIBCN [45] ceramics such as attract attention because they are used in absorbing materials . using The Poly blending ceramic method and chemical vapor deposition method to prepare Si 3N 4 -si (B) C (N) such as composite ceramics, and controls the component containing the amount [] -]] , Heat Treatment temperature [, 50-52], To introduce SiC nanoparticles [%] or multi-walled carbon nanotubes [Si] etc methods , effectively regulates their dielectric constant number , 6b Liquan etc [all] Summary SiC Ceramic Dielectric performance . The is currently applied to the base of a wave-absorbing structural ceramic matrix composites body with chemical vapor permeation SiC (CVI sic) and pioneer body impregnating cracking SIC (PIP sic) main .

3.3 Interface

because both ceramic fibres and ceramic substrates are typical brittle materials material , its own fracture toughness and plastic deformation to the toughness of composites the and the improvement of break work have little contribution .. So the interface is the key Unit for implementing its strong-toughening. The primary purpose of the interface design is to introduce a weakly bound interface in the ceramic ceramic matrix composites to prevent / deflection crack Purpose . current , have 3 The idea of a design interface the toughening of ceramic matrix composites : introduces the interface phase , introduces an interface null Gap , fiber / Porous Matrix interface , its deflection crack schematic diagram 7 [9] is shown in . introduces interface phase to improve bonding between fibers and substrates Degree is the successful development and application of ceramic matrix composites at present, with the validity path . Although the interfacial phase is less than the volume fraction of the composite.

in 10% , is a key factor affecting the mechanical properties of ceramic matrix composites factor [+]. The interface has a 3 key feature : Payload delivery , block crack ,deflection crack , to effectively implement this 3 features , requires The combination of fiber and substrate cannot be too strong or too weak [a , 56-57] , bounds The face should be of a certain thickness and have the same width as the fibers and the matrix. Thermodynamic compatibility [+]. pyrolytic carbon (PYC) and six square boron nitride(h-bn) The itself has a layered structure , reasonably designed to achieve the above functionality , is currently sic/sic most widely used in composites 2 interface phasematerial [C,].

(b) SiC Composite Ceramics

diagram 6 Doping trace elements reported in the literature SiC the dielectric properties of and SiC Complex dielectric properties of ceramics [+]

Fig. 6 The reported dielectric properties of sic powders doped by trace elements and sic composite ceramics[42]</b 30>

(a) interphase (b) fugitivecoating (c) Porous interface

diagram 7 3 interface-designed fibers / schematic diagram of crack deflection between matrices [9]

Fig. 7 microstructural concepts for enabling crack deflection at the Fiber/matrix interfacial region in Cfccs[9]</ b30>

3.4 Wave-absorbing structural ceramic matrix composites

Current high temperature wave-absorbing structure SiC Fiber-reinforced ceramic base complex Material Public report very little [6, 20 , $, 67-68], (*), [], * * * Related reports main focus on domestic KD type sic fiber toughening sic Ceramic base composite material material , Study its different process methods (like CVI, PIP , and so on) prepared bounds face (PYc , BN , and so on) and SiC matrix mechanics and suction of composites Effect of wave performance , Specific material composition and performance such as table 3 and diagram 8 show [69-81]. literature sic/sic composite electromagnetic ring The main feature is electromagnetic wave reflection , This is mainly because PYc boundsface [, , +] high conductivity , Cvi SiC interface []] or matrix [i] with high dielectric constant , dielectric loss Large , so ,sic/sic composite material The wave absorbing performance of the material is getting more attention . Mu etc [72-77 , ?? Mining with different interface materials , and doping to the matrix precursor ti3sic2 and Al2 0 3 A method of particles such as the "" Sic/sic Composite , to optimize its dielectric performance .

4. Outlook

sic/sic Composite is a high-temperature wave-absorbing structural ceramic base Composite research hotspots . to improve its mechanical and absorbing performancehave the following difficulties :1) CVI System-Ready sic/sic with good Good mechanical properties , but showing electromagnetic reflection characteristics , Wave-absorbing performance Poor , This is mainly because CVI SiC Matrix High Dielectric constant , Medium power loss large , cause Sic/sic Wave impedance mismatch for ; 2) PIP SiC low dielectric constant of the substrate , Low dielectric loss , is not for electromagnetic loss

Foot ; 3) on wave-absorbing structure sic/sic High temperature mechanics of composites Properties , Research on wave-absorbing performance and antioxidant properties .

1) Design materials should meet the characteristics of absorbing and mechanical properties matching principles ;2developing) wave type SiC fiber or by regulating the fiber surface state for fiber and fiber prefabrication with different electromagnetic properties Body ; 3) to use CVI to prepare a wave-type continuous dense ceramic matrix (like si3n4 etc), its matrix not only has high modulus and high damage tolerance limit , with low dielectric constant and low dielectric loss characteristics for the benefit of the meet impedance matching requirements , to further improve the mechanics of composites performance and wave-absorbing performance ;4) Use multilayer absorbing structure to increase suction Absorption of wave-structured ceramic matrix composites .

(a) permittivity

-14-16-

-18- ®

-20- A ®l 0 l 0 GHz 3 mm

140 160 180 200 220 240 260 280 300

Flexural Strength/mpa

(b) Electromagnetic wave absorbing and mechanical properties

diagram 8 Documentation [69-81] Wave-absorbing structure reported by SiC Fiber Toughened ceramics Base Composite (number See table 3) performance of Fig. 8permittivity,electromagnetic Wave absorbing and

Mechanical properties of sicfiberreinforced ceramic matrix composites reported in Literatures[25, 69-81]

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