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Preparation and mechanical properties of particle-reinforced aluminum matrix composites

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Abstract: briefly introduces the classification and development of metal matrix composites , and focuses on several common preparation methods of particulate reinforced aluminum matrix composites , includes stirring casting , Squeeze casting , Liquid metal infiltration , powder Metallurgy , jet deposition and newer in-situ reaction compounding method ; also reviews particle reinforced aluminum base Research progress on mechanical properties of composites , including experimental progress ,theoretical model and simulation progress ; Finally, the development direction of particle reinforced aluminum matrix composites is prospected ..

Keywords: metal matrix composites ; particle Enhancement ; Preparation Method ; Mechanical Properties

metal matrix composites (metal Matrix * Composites, MMCs) refers to metal , alloy or intermetallic compound, base body ,, and a composite containing enhancements . It's A new branch of the complex composite material , Although century 60 at the end of the decade , start a faster development , but metal matrix composites overcomingPoor thermal conductivity of polymer matrix composites , does not conduct a conductive , easy to suck wet , aging , To release small molecules such as a disadvantage , This class of material is also due to the higher than modulus and intensity , High temperature mechanical performance , Wear-resistant performance excellent , Low Thermal expansion factor , High dimensional stability , anti- features such as fatigue performance are widely used in aerospace , fields such as automobiles . such as tungsten fiber reinforced superalloy base composite material material available for aircraft engine parts , graphite / aluminum matrix composites is a good structural material for satellites and spacecraft [1-4] .

lightweight metal matrix composites generally include aluminum base , Magnesium base Titanium Base and its related alloy matrix composites . The difference between by enhancer form can be divided into whisker , short fiber , continuous fibers and bullets granular reinforced composites . compared to granular reinforced composites , fiberDimension reinforced composite manufacturing process complex , High processing temperature , performance fluctuation and high cost , failed to get large-scale industryapply ; The preparation process of particle reinforced metal matrix composites simple single , Low Cost , use conventional metalworking equipment to prepare , and also has a high intensity and modulus , and wear-resistant , Heat- resistant and corrosion-resistant properties , make particle reinforced metal base complex

The composite material has attracted the attention of researchers and has caused significant commercial warm [5-9]. The selection of specific enhancement phases is based on the composite's purpose , factors such as process and cost comprehensive consideration . current often with enhanced material oxides (such as SiO_2 , Al_2O_3 , and so on), nitriding things (TiN,AlN and Si 3N4 etc) and most widely used "" (like SiC, TiC , and so on).

particulate reinforced aluminum matrix composites (particulate reinforced aluminum matrix composites, Pramcs) with its matrix alloy selectable range , low cost , Easy to use traditional craft Legal preparation and processing ,

enables batch and mass production , preparation The materials for exhibit good dimensional stability and isotropy, and

the Spotlight . For example , by Shandong University and Qufu Kingsky Pistons Co., Ltd. co-developed SiC_p /al composite pistons should Engine for motorcycles and small cars [ten]. Beijing Aviation material Material Research Institute of particulate reinforced aluminum matrix composites has been applied to Camera parts of satellite [one] ,with a previously designed titanium alloy material greater than , lower weight 35% The heat transfer performance of the part is increased by for approximately ten times ,and has been applied to the Chinese ' Resource Second Guardian star . The United States and other developed countries have made particulate reinforced aluminum base compound material applied to military fighter's pelvic fin [[]], compared to traditional aluminum material , It increases the stiffness of the material 50°%, and Service Life also from the previous h to the 6000 H . other , with precision casting for , , extrusion Casting and Powder metallurgy

particulate reinforced aluminum matrix composites , can reduce stress release Create a Variant , improve dimensional stability of material , also with high intensity , damping Harmony frequency , reduce vibration and put Large , to improve system accuracy as a structural part of the inertial navigation system stability [a]. United States has adopted a volume score of 40% SiC particle enhancement Al-6061 Alloy composites replace Trident missile [previous AISI 416 Universal joint of stainless steel manufacturing ,, and take advantage of SiC particle reinforced aluminum matrix composites replace beryllium alloy Manufacturing Inertial navigation device . above indicates , particle reinforced aluminum the base composite is already important in both military and civilian industries. application .

1. method for preparing particulate reinforced aluminum matrix composites

The process of producing particulate reinforced aluminum matrix composites at present The method can generally be divided into the following four categories : Liquid process (stirring casting , Squeeze Casting , , liquid metal infiltration, etc.), Solid State (powder Metallurgy law etc), bi-phase (semi-solid processing , Spray coprecipitation etc), with And in- situ compounding . The has only a few typical preparation procedures. method and features simple comments .

1.1 Stirring Casting method

The stirring casting method is to add the enhanced phase to the matrix metal liquid ,, make liquid and solid phase by high speed rotating mechanical mixer Mixed Evenly, then pouring into spindle [14-16] . This method is closed to Distribute the enhanced phase evenly across the matrix , and the matrix and the add The interface between the strong phase is good . Stirring casting method into liquid phase mixing method and liquid solid two phase stirring method . vs. other preparation technology more than , There are many advantages to the mixing casting method . such as : low manufacturing cost , easy to shape complex artifacts ; Process equipment relatively simple , fit mass production . But stirring casting still exists Some questions , If the ceramic particles are prone to bias in the stirring process gather , , interface easy to react, etc. . second ,Non vacuum stirring casting build time , easy to introduce gas in stirring process , To make the product The section produces a stoma . again , Using this method to make metal base composites , volume fraction of particle enhancement phase will be subject to a certain restrictions .

1.2 Squeeze Casting

Squeeze Casting (also known as preform infiltration) first by pressing make an enhancer into a prefabricated block with the shape of the part , put in cast ,

Pouring liquid metal or alloy under gravity , then pressure , make base body melts into ingots of prefabricated blocks [[]]. Cang Mask etc [[] take Squeeze Casting for enhanced volume to 45%~50% and excellent performance SiCp/A 1 composite material . Composite Physics performance data almost consistent with theoretical predictions , this saysGood uniformity of materials , no obvious flaw . This is because [SiC particles with Al The

interface of the matrix combines well , Interface can be to pass to load , Can well suppress the Al The expansion of the matrix , and less thermal resistance of the interface , binding very close .

Product size accuracy by squeeze casting , does not require complex post-processing ; Liquid Metal infiltration time is short , Cooling Rate more quickly , to reduce or even eliminate granular interface reactions ; enhance phase volume fraction adjustable range . But squeeze casting process complex , difficult to prepare complex workpiece and low content particles strong metal matrix Composites , and when the infiltration pressure is very high , to has a significant effect on the integrity of stencils and workpieces .

1.3 Liquid Metal Infiltration

In this method of preparation , enhancements need to be in advance with the appropriate Binder Bonding , then cold pressing to a certain shape and size pre workpiece ,then drying [A] . before infiltration , First pre workpiece heating to 600~800 °C , and then place it in the preheated gold The appropriate position of the pressure type ,pouring into refined molten metal , Use vacuum or pressure method , make molten metal liquid into prefabrication box , stay for a while , Wait until it's solidified . The required particle reinforced aluminum matrix composite workpiece .

the preparation process and equipment for this method are simple , made to This lower , at the same time avoid the occurrence of enhancements and matrix not infiltrating the behavior , The material density is more uniform , molten metal cooling Fast , Preparation process cycle short , eases granular interface reactions , Materialmaterial performance is higher . However, it is difficult to prepare a certain void in the method of , granular preform , another , A base exists in the manufacturing processcombination of body and particles , infiltration process parameters not easy to control , When pressure is too high it may break the prefab, does not create shapes complex artifacts , Therefore, the application of this process is subject to certain restrictions .

1.4 Powder Metallurgy

Powder Metallurgy was first developed for the preparation of particle enhancement metal matrix composites process [20-21]. It is a metal powder and a enhanced Ceramic particle etc screened , uniform blending , cold-Compaction consolidation ,

degassing , sintering , , as well as subsequent processing of composite materials, a process . diagram 1 giving powder metallurgy Preparation SiC Enhanced aluminum base complex composite Material traditional process preparation process . sintered sample passes hot extrusion can reduce the number of voids , Refine Grains , Improve Complex binding Material interface strength and SiC distribution of particles , so to improve the mechanical properties of composites effectively . after heat treatment (likeSolid solution , " quenching and aging ") can further harden the composite after mechanical Properties . The advantage of the powder metallurgy method is that it is easy to prepare a reinforced "" metal matrix composite with high content , and easy to control uniformity of the distribution of particles in the matrix , prepared metal matrix composites A more stable performance metric than other methods . another , Compared to the same material produced by molten metal process , with powder metallurgycomposite strength of particulate reinforced aluminum matrix composites prepared by gold process level is higher , Material's microstructure improved . but is The process and device is more complex , Degassing is not complete causes a hole in the inside of the material, Improper temperature selection also causes ???. also , This method is difficult to produce a net size 0 part item , also does not apply to production of larger sizes , is not appropriate for mass production of aluminum matrix composites .

1.5 Spray Deposition

The spray deposition method is to melt the metal substrate in inert gas body stream atomization , Add enhancer powder at the same time , to make both in the fog In- mixer , then jointly deposited on preprocessed substrates , to make

composite material [].This method is characterized by an enhanced body integral number can be adjusted arbitrarily , The granularity of the enhanced body is also unrestricted
System . because the enhancer is in contact with the matrix molten fluid is relatively short , The reaction between the two is easy to control, significantly improved interface combination Status , allows the substrate to hold atomized deposition , Fast Frozen features , and grains are very small . preparation costs for spray deposition between powder metallurgy and casting .

1.6 In- situ compositing

in-place multiplexing works by creating a powder mixed with matrix powder , then after a certain deal , makes the Two powders react , generate dispersion in matrixStrong phase [a]. diagram 2 to take advantage of Al and Ti Mutual spread , in-place reaction generation a new " nuclear shell "" structure enhancement phase [24] . its soft Core "{" (+) (), "" () * and Matrix Al to combine hard metal with things " Shell The folder in the middle , can increase the strength of the composite by at the same time , to Preserve material ductility [a] . The method of in-place-complex/is a good way to solve the leaching of augmented body and metal substrate Run problem , enhancer has good knot with metal substrate interface close and thermodynamic stability ; at the same time if the enhancement phase particle is fine Small , distribute evenly in the matrix, Enhanced Good . another , The microstructure of the material can be adjusted by changing in-situ growth process parameters structure , reduce the cost of raw materials ,has been extensively closed Note . but , in- place Composite also have disadvantages , such as enhancements points and volume fractions not easy to control , A process is harder to master .

To summarize , Casting particle reinforced metal base complex Composite material process simple , low cost , for industrialized high-volume births production , but not for composite materials that produce small granular high volume fractions material , with more product defects . jet deposition prepared metal matrix Composite material can be arbitrarily adjusted enhancement phase volume fraction , and Increase The interface stability between the strong phase and matrix is better , But this method high cost of preparation , process complex . Powder Metallurgy Preparation metal matrix composites , The matrix has a good combination of enhanced interface , But the device is complex , process cumbersome , High Cost , and enhanced granular easy on Reunion , The material performance is difficult to achieve uniformity . in -place reverse to prepare metal matrix composites simple process , Low Cost , and

The interface between the enhanced phase and matrix is obtained by reacting without pollution , Two-phase binding strong . addition, in - situ reaction Fasheng The enhanced phase of is not easy to grow up , Small size , So in- situ reactions The method is a promising development. A method for preparing metal matrix composites .

2. Mechanical properties of particle reinforced aluminum matrix composites

2.1 Experimental Research

2.1.1 elastic modulus

modulus of elasticity is after the composite is added to the particle enhancement phase plus the most significant mechanical properties . influence particle reinforced aluminum base compound material modulus of elasticity includes particle reinforced phase shape , volume fractions and distributions . modulus of elasticity generally increases with the Increase in the volume fraction of the size of the enhanced "" , to enhance the shape of the phase to Its effect is not yet clear . In addition it is related to measurement methods , example such as : General modulus of elasticity measured by dynamic measurement method The extension of the draft Test for static measurements from stress / strain curve Elastic section measures large , Whether the test method is extruded or compressed also affects the value of the [[] .

2.1.2 strength and hardness

strength and hardness are people studying particle reinforced aluminum base compound One of the most concerned mechanical properties of the material is the . The addition of enhanced particles can significantly improve the strength and hardness of the composite. . influence composite material main factors for strength and hardness include : matrix type , enhanced type of body and volume fraction of enhancer , dimensions and distributions State .

Research has shown that , for soft substrate (like Al-1100 "and Al-6061) composite material , SiC Increase in the volume fraction of the particles Make composites get a high enhancement rate , But when volume is increased The strength of the composite decreases when is long to a certain value [?] ; and to Hard matrix (like Al -7075 and Al-2024), SiC The is joined and does not significantly increase the strength of the composite. [] . Williams etc [+] in the particle size to SiC Enhanced 2080 aluminum matrix composites pull Effect of extension deformation and fracture mechanism found , compound The strength of the material increases with the decrease in particle size , This is by on small size SiC The inner particles contain less intrinsic defects reason . Lewandowski wait [[] Research with Al-7Zn -2Mg-2Cu -0.14Zr to Matrix , Volume score is 20°% 'sSiC particle for reinforced composites when found , when SiC particle size from 5 mm increase to mm when , Its distribution uniformity in the matrix "" high , Composite mechanical properties are better .

Most other aluminum alloy substrates are aging-hardened aluminum gold . during the aging heat treatment process after solution quenching , because of The addition of the SiC causes the substrate dislocation density to increase, and the Matrix is gold precipitation rendezvous along dislocation non-homogeneous nucleation and growth ,causes the composite " aging Acceleration , Phenomenon . Song etc [to] through the experiment and simulate Discovery , When composite material contains SiC Enhanced particles Scale to Ten mm,, aging temperature is 175 °C on , SiC Enhanced Al -10Si -0.5 Mg The yield strength of the alloy composite is in the aging Any stage of the procedure is increased with The increase in the volume fraction of the SiC and add , simultaneous SiC Increase in particle volume fraction also speeds up Aging Procedures ,time limit for composite material reaching peak age Short , as shown 3 show .

the needs to point to the , Matrix material system , processing conditions and test method relationship to composite strength and hardness and not sure . on the other hand , temperature and environment will be on composite material material strength and hardness effects , But they are strong for composite materials the specific mechanism of the degree is pending further study .

2.1.3 Plastic

Another important mechanics of particle reinforced aluminum matrix composites Performance is the plasticity of the material . Particle enhancer added at the same time to improve aluminum Base composite strength and hardness while , also creates its plasticity down . in other words , reference to strength and hardness of composites high ,at the expense of plasticity .

Llorca , and so on [a] A study of shows that , particle reinforced aluminum base compound

The plasticity of the material is proportional to the plasticity of the Matrix . in addition to, its plasticity not only with particle enhancement phase / The strength ratio of the matrix is relative to also The and enhanced particle shape and space distribution are related to . Umit and Kazim [next] through granular SiC enhanced Al -5°% Si -0.2 °/ 0 Mg The test of the Composite is conducted to study the strength of the composite by hot extrusion and ductility effects . on ° C ° Next , with 10:1Extrusion than extruded composite ingots , through its microstructure test for observation and mechanical performance ,Results show that the extruded organization is more homogeneous than the cast microstructure , The level of ductility is also greater than Large elevation . Lloyd[+] research shows , enhance the body of the particle credits in 12% to 18% particle reinforced aluminum matrix composites between material , get better strength , with good plastic water - ping . also , Some researchers change the particle enhancement phase by using the structure , If nuclear is soft phase Fe or Ti, shell with higher hardness The core-shell structure of the intermetallic compound, , to limit the expansion of the crack , Increase the strength of the composite at the same time , dramatically improve material's plastic

- sex , get excellent mechanical properties [],,.

2.1.4 fracture toughness

fracture toughness characterizes the ability of the material to resist fracture deformation Force . fracture toughness ^. generally decreases with enhanced particle size or Increase volume fraction . Particulate reinforced aluminum base composite materials The nucleation of the crack in the material generally occurs in the segregation zone of the particles , core The critical stress is not determined by the total volume fraction of the enhanced particles , is determined by the volume fraction of the local enhancement particle . Majority The scholars believe that the break is caused by the breakage of the particles or between the matrix and the particles of the off-glue causesthe , large particles in high strength substrates tend to break crack low -strength matrix holes preferentially in interface core .

book name, and so on [+] after hot extrusion SiC / Al 2024 Composite Material Research findings , composite fracture toughness and SiC The aspect ratio and volume fraction of the grain have a lot to do with .. when SiC particle Volume fraction from 3% Add to 18% when , material fracture toughness sex from 20.16 MPa -$m^{1/2}$ down to 14.67 MPa -$m^{1/2}$, As shown in figure 4 , is shown . Song wait [Panax] passes the SiC particle Enhancement Al - cu-mg Testing of composite materials indicates that , fracture toughness of composites with the SiC Increase in particle volume fraction , and the Evolution of the fracture toughness and the evolution of the yield stress in the time limit are reversed , Increase Add aging temperature to increase fracture toughness of composite materials the lowest value .

diagram 4 sic/al2024 fracture toughness in composites with SiC particle volume fraction variation [+]

2.2 parsing Model

2.2.1 blending laws

the modulus and yield of the particulate reinforced aluminum matrix composites intensity approximately follows mixed law [38-39] , can be represented as

$E_c = V_m E_m + V E$ (1)

s YC = V m sym V + R S yr (2)

where E . , all the same as E[m] * * * representing composites , Enhanced body and base body's modulus of elasticity ,S y . , Syr vs S ym are composites , strength of the body and matrix yield intensity ,V[] and Vm respectively Enhancements and matrix volume fractions . due to the equivalent strain of the blending law false set to SiC_p/al Composite not valid , with mixed set Law Forecast SiC_p/al The modulus of elasticity and yield strength of the actual value significantly different . also , because the blending law does not consider enhancements Effects of microstructure on performance with shapes , typically forecast for this model The mechanical performance value of the is the upper limit of the experimental value .

2.2.2 Shear Lag model

Shear lag model and modified shear lag model , its The Physical principle is based on the soft aluminum matrix The stress that is exerted on the outside is "" hand HardSiC enhancements on , make composite elastic die volume and yield stress increased . The effect of the was first made by Cox[?] The presents the , followed by the Nardone , and so on [41-42] fixup , Send The shows the revised shear lag model . based on modified shear lag model , SiC The yield stress of the reinforced aluminum matrix composite can be expressed to

$F [V_p(A + 2)/2 + V_m]$

where S Cy represents the yield stress of composite materials , S My is a matrix Gold intrinsic yield stress , 乂 SiCthe length diameter ratio of the particles ,V and V m represents SiC volume fractions of particles and matrices .

Song , and so on [%] combined with particle invalidation , Weibull Statistical Distribution + Eshelby equivalent inclusion theory , To consider particle invalidation modified shear lag model . from the diagram 5 to see , in the research tracing SiC particle enhancement Al-6.4%Zn-2.3%mg alloy composites when , compared to traditional modified shear

lag model , taking into account the modified shear lag model for the calculation of the predicted yield stress with the "" Experimental results agree better . as SiC increase particle volume score plus , the traditional modified shear lag model predicts a composite of theyield stress deviations from experimental values more and more clearly , to consider particle loss the modified shear lag model for the effect is more consistent than the experimental value .

2.2.3 Eshelby Model

Eshelby The model is Eshelby equivalent inclusion theory [a] is base , after Mori , and Tanaka mean stress field theory revision after [45-46] established . The model can successfully predict the length of the smaller than the small of whisker reinforced or particulate reinforced metal matrix composites with stiffness and intensity , It also explains the effects of thermal residual stress on mechanics of materials performance effect . Eshelby equivalent inclusion theory is based on false All the stresses that are fixed at all points in the enhanced body are the same . root according to Eshelby equivalent inclusion theory , will SiC particle modulus of elasticity transition to elastic modulus of matrix material , The internal stress generated by the can be is represented as

ai = Ci ($_e^C$-$_e^T$*) = C_M ($_e^C$- e^T(4))

where C ^ PCm is SiC Elastic constants of particles and matrices amount ,e^C is a constrained strain tensor , e^T * is SiC particle transitions should be

Tensor , e^T The transition strain tensor for the matrix is . when applied stress to s_A when , a S 1C The force of the particles is

^ c = ^ I + ^ A = ^{C} M ((^ - ^) + ^{C}M ^

= ^{c} m (e^c+e^A -e^T[]) (5)

where e^A is the plastic deformation of the matrix material under applied stress . when the base the Body contains more than one SiC particle and matrix is not infinite , toConsider boundary conditions , introduce mirror force Si_m =$c_m e^m$, Then SiC @ The force that the grain is subjected to in addition to the load can be expressed as a

o C = 0 ! + o A + o $_{im}$ = C m (e^C + "" (No) () (e) ^{A}+ e M - e^T)) (6)

e ^{T} =-[(- i[S-)[-/(S -/)]-CM]$^{-1}$.

[-(C , - C m) s ^{a} /C m] (7)

e^c = S e^T (8)

$_e^M$ = - F (S -1) e^T (9)

where I is the unit matrix , / is SiC particle volume fraction , S is Eshelby count .

Lloyd by comparing the obtained from the literature SiC particle Enhancement

experimental values and mixing laws of elastic modulus of aluminum matrix composites ,

Eshelby model and Halpin-tsai The computed value of the model indicates that ,

The modulus of elasticity derived from the mixed law is larger than the experimental value , and

Fixed Halpin-tsai model and Eshelby Model computed value

is closer to the experiment value [%] , As shown in figure 6 shows .

diagram 6 elastic modulus with SiC change in particle volume fraction ^ is the length-diameter ratio of the particles

2.3 Finite element calculation

because the method of finite element analysis can consider granular enhance body shape , size , Distribution and volume score , and break crack characteristics to composite stresses / effect of strain behavior ,

The simulation results are close to the experimental value , To make this method subject to the Everyone's attention , application is also getting wider .

Xu Na [all] the uses planar strain and axisymmetric two kinds of single cell model , Analysis shapes different SiC enhanced particle toT6 at Effects of the mechanical behavior of the aluminum matrix composites by . The result shows

that , With the increase in the number of edges of the enhanced particles , Composite yield strong degrees are gradually lowered . Sun Chao etc [[ ] using finite element method and Axisymmetric single cell models simulate SiC Enhanced body shape , volume score and Effect of different substrate types on mechanical behavior of aluminum matrix composites . results show : Stress concentrations appear at sharp corners of the enhanced body ; elliptic columns the strongest ability to transfer loads in the form enhancer , The best hardening effect ; Increase the volume fraction of the enhancer, cause particle spacing minus small , geometry must dislocation free motion path reduction , composite material , material strength increases . Chawla wait [$] to visually limitMeta Method Research SiC particle enhancement 2080 aluminum matrix composites mechanical Properties , simulate three different structural units (sphere ,) cuboid and contains Microscopic unit of particles) on SiC particles to The contrasts with the results of the experiment . from the diagram 7 to see , third architecture units (14 A microscopic unit of particles) complex The mechanical properties of the composite materials are consistent with the experimental results ..

0.000 0.005 0.010 0.015 0.020

Strain/%

diagram 7 Comparison of simulated and experimental values of three different structural units [$]

3. Outlook

particle reinforced aluminum matrix composites in recent years has been a researcher 's attention and cause great business enthusiasm , except for it Method Direct Research , improving particle reinforced aluminum matrix composites intensity , elastic modulus , ductility and fracture toughness , properly deploy each relationship between mechanical properties , should also be mechanical and physical Hardening mechanism and fracture mechanism of composite materials . This requires the

based on previous experiments and physical models , System Considerations Composite Material Various variants of material , further modified , Refine and develop newphysical model , combined with finite element analysis method factors that affect the mechanical properties of composites by increasing Research efficiency . particle reinforced aluminum matrix composites after the main research research Direction should be the experimental method , physical model and fem Analysis Method Organic combination , to promote composite material research Show , and shorten the research cycle for new materials design .

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