Numerical Experiment of the Solid Particle Erosion of Bionic Configuration Blade of Centrifugal Fan

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In this paper, a bionic method was presented to improve the erosion resistance of blade of the centrifugal fan. A numerical investigation of the solid particle erosion on the standard and bionic configuration blade of 4-72N_Q10C centrifugal fan was presented. The numerical study employs computational fluid dynamics (CFD) software, based on a finite volume method, in which the discrete phase model was used to model the solid particles flow, and the Eulerian conservation equation was adopted to simulate the continuous phase. Moreover, user-defined function was used to define wear equation. The various diameters of the particles were taken into account. The positions of collision of standard and bionic fan blades were discussed, and two kinds of centrifugal fan blade wear were compared. The results show that the particles from the incident source with different positions have different processes of turning and movement when enter into the impeller. The trajectories of flow in the fan channel are significantly different for the particles with different diameters. Bionic fan blade have lower erosion rate than the standard fan blade when the particle size is 20 μm . The anti-erosion mechanism of the bionic fan blade was discussed.

KEY WORDS: Bionic; Numerical simulation; Centrifugal fan blade; Erosion resistance

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1. Introduction

Solid particle erosion is a process of material damage caused by hard particles striking the surface, either carried by a gas stream or entrained in a flowing liquid. Sharma and Babu *et al.*^[1,2] have reported that damage caused by erosion in several industries has a wide range of situations. Material failure is usually caused by corrosion, wear and mechanical damage. According to the research of Wang *et al.*^[3], the erosion holds about 8% of regular wear in industrial production. Working medium of centrifugal fan contains large amounts of solid particles with very high speed, impacting the surface of blade and housing, which causes erosion. The erosion of the blade may cause a serious consequence, in which the flow characteristics of the fans are greatly exacerbated, and often result in the blade fracture, runaway and the other main failures. The researches in the material

erosion are focused on the study of mechanisms, factors of the erosion and the optimal selection of the materials which play a significant role in saving materials, reducing energy consumption and improving economic efficiency^[4-8].

It has been concluded by previous researcher^[9-13] that enhancing the wear resistance of the material surface using resistant materials or coating material with better wear resistance is the general methods to reduce erosion. These methods will result in cost increasing.

In recent years, the effects of bionics have attracted many attentions^[14-16]. Han *et al.*^[17] found that some animals in nature such as desert lizards and scorpions, living in the sand and other gas/solid mixed-media environment, exhibit an excellent anti-erosion function using synergistic action of special surface morphology, internal microstructure and biological flexibility. Fig. 1 illustrates the design ideas of the bionic fan blade.

Many of the factors dominate the rate of erosion, such as particle velocity or particle mass flow rate, particle diameter, impact angle and particle distribution, which can result in different flow conditions of

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Fig. 1 Design ideas of the bionic fan blade: (a) surface morphology of desert scorpion (b); 3D model of erosion resistance; (c) bionic fan blade

the system. Many practical examples indicated that the change of the flow conditions will result in a great increase or decrease of the erosion.

The experimental study on the dynamic behavior of the solid particles usually requires special equipment and methodology. Also, the erosion process is a complex problem and hard to obtain a mathematical formula to account for the factors which affect the rate of the erosion. This paper presents a numerical study of the erosion process of centrifugal fan blade by computational fluid dynamics (CFD), in which the various diameters of the particles were analyzed, the positions of collision of standard and bionic fan blade were discussed, and erosion resistance of two kinds of centrifugal fan blades were compared.

2. Description of Analysis

The numerical study of the erosion process using CFD considers a mathematical model with Eulerian conservation equations in the continuous phase and a Lagrangian frame to simulate a discrete second phase. The dispersion of the particles in the fluid phase can be predicted using a stochastic tracking model which includes the effect of instantaneous turbulent velocity fluctuations on the particle trajectories.

2.1 Governing equations

The computational domain considers the mass conservation and momentum equations for incompressible flow in a 3D geometry in a steady state. The mass conservation is

$$\nabla \cdot \rho v = S_m \quad (1)$$

where ∇ is operator nabla, ρ is density, v is velocity, S_m is the mass added to the continuous phase from the dispersed second phase. The momentum equation is

$$\nabla \cdot (\rho v v) = -\nabla p + \nabla \cdot \tau + F \quad (2)$$

where p is the pressure on fluid micro unit, τ is the stress tensor and F is the force that arise from interaction with the dispersed phase. For turbulence, the numerical study includes the standard k - ε model^[18],

where the turbulent kinetic energy (k) equation, is expressed by

$$\frac{\partial(\rho \kappa u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_i}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k - \rho \varepsilon \quad (3)$$

and the dissipation rate (ε) equation, is expressed by

$$\frac{\partial(\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_i}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} G_k - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} \quad (4)$$

where u_i is velocity on the direction i , x_i and x_j is the distances coordinate on the direction i and j , μ is the molecular dynamic viscosity, μ_i is the μ on direction i , G_k represents the generation of turbulent kinetic energy due the mean velocity gradients, $C_{1\varepsilon}$ and $C_{2\varepsilon}$ are constants ($C_{1\varepsilon}=1.44$, $C_{2\varepsilon}=1.92$), and σ_k , σ_ε are the turbulent Prandtl numbers for k and ε ($\sigma_k=1.0$, $\sigma_\varepsilon=1.3$), respectively.

2.2 Discrete phase model (DPM)

This model allow us to simulate a discrete second phase in a Lagrangian frame of reference, where the second phase consists of spherical particles dispersed in the continuous phase. The coupling between the phases and its impact on both the discrete phase trajectories and the continuous phase flow is included. The turbulent dispersion of the particles is modeled using a stochastic discrete-particle approach. This approach predicts the turbulent dispersion by integrating the trajectory equations for individual particles, using the instantaneous fluid velocity. The prediction of particle dispersion makes use of the concept of the integral time scale, T_L , which describes the time spent in turbulent motion along the particle path. This time scale can be approximated in the standard k - ε model as

$$T_L \approx 0.15 \frac{k}{\varepsilon} \quad (5)$$

The trajectory of a discrete phase particle can be predicted by integrating the force balance on the particle, which is written in a Lagrangian reference frame. This force balance equates the particle inertia with the forces acting on the particle.

$$\frac{du_p}{dt} = F_D(u - u_p) + F_{\text{other}} \quad (6)$$

where u_p is the particle velocity, t is time, u is the fluid velocity, F_{other} is the additional force, the drag force per unit particle mass is $F_D \times (u - u_p)$, and F_D is defined as

$$F_D = \frac{18\mu}{\rho_p d_p^2} \frac{C_D Re}{24} \quad (7)$$

where ρ_p is the particle density, d_p is the particle diameter, C_D is the drag coefficient, Re is the relative Reynolds number.

The F_{other} in this case is compounded by the force required to accelerate the fluid surrounding the particle, defined as

$$F_{\text{other}} = \frac{1}{2} \frac{\rho}{\rho_p} \frac{d(u - u_p)}{dt} \quad (8)$$

which is important when $\rho > \rho_p$, and an additional force due to the pressure gradient in the fluid

$$F_{\text{other}} = \frac{\rho}{\rho_p} u_p \frac{\partial u}{\partial x} \quad (9)$$

The Re is defined as

$$Re = \frac{\rho d_p (u_p - u)}{\mu} \quad (10)$$

where the C_D is applied for smooth spherical particles.

To incorporate the effect of the discrete phase trajectories on the continuum, it is important to compute the interphase exchange of momentum from the particle to the continuous phase. This exchange is computed by examining the change in momentum of a particle as it passes through each control volume in the computational domain.

This momentum change M is computed as

$$M = \sum \left(\frac{18\mu}{\rho_a d_p^2} \frac{C_D Re}{24} (u_p - u) + F_{\text{other}} \right) \dot{m}_p \Delta t \quad (11)$$

Finally, to evaluate the erosion rate at the wall of the blade, applying the discrete phase model, it is important to define parameters such as: the mass flow rate of the particle stream, $\dot{m}_p$, impact angle of the particle path with the wall face α , function of the impact angle $f(\alpha)$, and the area of the wall face where the particle strikes the boundary A_{face} . The erosion rate R_{erosion} is defined as

$$R_{\text{erosion}} = \sum_{p=1}^{N_{\text{particle}}} \frac{\dot{m}_p C(d_p) f(\alpha) v^{b(v)}}{A_{\text{face}}} \quad (12)$$

where $C(d_p)$ is a function of particle diameter, α is the impact angle of the particle path with the wall face, $f(\alpha)$ is a function of impact angle, v is the relative particle velocity, $b(v)$ is a function of relative particle velocity, and A_{face} is the area of the cell face at the wall. In Eq. (12) the impact angle function was defined by a piece-linear profile and the diameter function and velocity exponent function are 1.8×10^{-9} and 2.6, respectively^[18].

2.3 Computational domain and grid

2.3.1 Modeling of centrifugal fan

Geometric construction and meshing were performed by AUTOCAD and GAMBIT. In order to ensure that the airflow in current collector has a steady state, a section of pipe modeling of the centrifugal fan was added in the front of the current collector. At the same time, in order to ensure the flow fully develop

at the exit, and to avoid the calculation reflux, a section of pipe was also added at the volute exit. According to engineering experience, the length of the outlet pipe is generally 4–6 times longer than that of the object features. In this paper, at the outlet of the centrifugal fan, the length of the lengthened pipeline is approximately four times than the characteristic length of the volute outlet. The extension pipe length of air inlet is twice as much as the inlet diameter of current collector. Fig. 2 shows the computational domain of the integrated model of fan.

The clearance between the blade import and the current collector were treated as 0, the thickness of each part of the fan were made proper dressing. The region from the current collector inlet to the spiral case outlet was defined as computational domain. The fluid flow channel of fan was divided into three regions: flow of current collector, impeller, and spiral case flow.

The origin is in the center of the current collector inlet, the negative direction of z axis is the direction of current collector inlet, the positive direction of x -axis direct to the spiral case outlet.

Standard and bionic fan blades are shown in Fig. 3 and Fig. 4, respectively. Fig. 5 presents the sectional view of the bionic blade. The profile of groove is ellipse. The lengths of semi-major and short half axis are 10 and 5 mm, respectively. The groove spacing on the arc in the same section is 20 mm. Fig. 6 presents 3D computational domain of the centrifugal fan.

2.3.2 Mesh generation

Different mesh types and sizes were used in each region, owing to difference in structure of each part and the flow patterns. Fig. 7 is mesh refinement on

Fig. 2 Simulation structural diagram of centrifugal fan

Fig. 3 Standard fan blade

the blade surface. Table 1 is the results of mesh generation.

2.4 Calculation Model and Boundary Conditions

Velocity-inlet boundary condition was used in the

Fig. 4 Bionic fan blade

Fig. 5 Sectional view of the bionic blade: (a) standard fan blade; (b) bionic fan blade

Fig. 6 3D computational domain of the centrifugal fan: (a) channel model of current collector; (b) channel model of impeller; (c) channel model of spiral case

Fig. 7 Grid near the fan blade: (a) standard blade; (b) bionic fan blade

entrance of the fan. Pressure outlet boundary condition was used in the exit of fan. The definition of the turbulence parameters based on turbulence intensity and hydraulic diameter.

The velocity of air flows in the tunnel entrained with solid particles is 11.6 m/s. The injection type was set to the surface. The solid particles with 1500 kg/m³ density were released from the inlet with an initial velocity of 11.6 m/s and assumed no slip between the particle and fluid. The particle diameters are 20, 50 and 100 μm , respectively. And the mass flow rate is 2 kg/s.

Internal flow field of the fan was assumed to be incompressible steady flow. k - ε model was used as turbulence model. Standard wall function method was used near the wall. Solid wall boundary was assumed to be no slip with wall roughness of 0.5. The interface boundary condition was applied for the interface of fluid region.

SIMPLEC algorithm was used for velocity-pressure coupling. The different equations were discretized by a first-order upwind differencing scheme. A convergence criterion of 10^{-3} for each scaled residual component was specified for the relative error between two successive iterations.

Open the two-phase coupling calculation in the settings panel of discrete phase model. The boundary of reflect was applied for the wall, and rebound model

Table 1 Each computational grid information of centrifugal fan

Region of fan	Lengthened segment of air inlet	Lengthened segment of air outlet	Current collector	Spiral case	Impeller	
					Standard blade	Bionic blade
Grid type	Hexahedral grid	Hexahedral grid	Hexahedral grid	Tetrahedron grid	Tetrahedron grid refinement	Tetrahedron grid refinement
Cells	223816	498200	48760	1830419	2000671	2089127

was expressed by Eq. (13). Calculation model of erosion rate was denoted by Eq. (14), the model for coal ash particles impacting steel was achieved by UDF.

$$\frac{V_{n2}}{V_{n1}} = 1.0 - 0.4159\beta_1 - 0.4994\beta_1^2 + 0.292\beta_1^3 \quad (13)$$

$$\frac{V_{t2}}{V_{t1}} = 1.0 - 2.12\beta_1 - 3.0775\beta_1^2 - 1.1\beta_1^3$$

where, V_n and V_t (m/s) are the normal component and tangential component of particle collision surface speed, respectively. The subscript 1 and 2 denote the amount before and after the collision. β_1 is the angle between the particles speed and the surface tangent before the collision, and β_2 is rebound angle of particles after the collision, and the unit is rad.

Experimental measurements reported by Tabakoff *et al.*^[19,20] indicated that the erosion of a target material was found to be dependent upon the particle impact velocity and its impingement angle. Experimental measurements were obtained for coal ash particles impacting steel at different impacting velocities and impingement angles. The experimental data were used to establish the following empirical equation for the erosion mass parameter, P_e , which is defined as the ratio of the eroded mass of the target material to the mass of the impinging particles

$$P_e = K_1 R_w^2 V_p^2 \cos^2 \beta_p (1 - R_T^2) + K_3 (V_p \sin \beta_p)^4$$

$$R_w = 1 + C_k \left(K_2 \sin \left(\frac{90}{\beta_0} \beta_p \right) \right) \quad (14)$$

$$R_T = 1 - 0.0016 V_p \sin \beta_p$$

where V_p and β_p are the impact velocity and impingement angle, respectively. β_0 is the maximum erosion angle, R_T is the tangential recovery ratio. The following values were used for the variables in Eq. (6): for $\beta_0 = 25^\circ$ (angle of maximum erosion)

$$\begin{cases} C_k = 1 & \beta_p \geq 2\beta_0 \\ C_k = 0 & \beta_p < 2\beta_0 \end{cases} \quad (15)$$

with K_1 , K_2 and K_3 material constants which are found to be $K_1 = 0.5225 \times 10^{-5}$, $K_2 = 0.266799$, $K_3 = 0.549 \times 10^{-12}$, $\beta_0 = 25^\circ$.

3. Results and Discussion

3.1 Analysis of particle trajectories

Fig. 8 present the track lines of the fan. The

Fig. 8 The path lines of centrifugal fan **Fig. 9** The trajectories of the particles in the impeller: (a) particle size of 20 μm ; (b) particle size of 50 μm ; (c) particle size of 100 μm

tracks of three kinds of the particles (20, 50 and 100 μm) are shown in Fig. 9(a), (b) and (c).

Particles with the air flow entering into the

impeller region from the current collector in axial direction, regardless of particle size, will make a 90° turn to enter the impeller channel. Particles from the incident source with different positions have different processes of turning and movement when enter into the impeller.

Some of the particles can directly enter the impeller channel from the current collector. Some particles will enter the impeller channel after rotating with the flow in the importing region of blade. The trajectories of flow in the fan channel are significantly different for the particles with different diameters. When the particles with the size of 20 μm into the impeller, they move along the blade pressure surface, in which a small number of them will impact to the blade leading edge and pressure side. Their trajectory is very close with the gas flow field, this is because the small particles mainly experience viscous dragging force of the gas, and the centrifugal force is relatively small. Small particles in the flow field tend to be fluid character, and follow the air movement. When the particles with the size of 50 μm travel into the impeller, the solid particles will impact to trailing edge of the blade by greater inertia, then turned into the impeller channel due to the larger mass and the non-ignorable inertia. Besides, the trajectory and the flow line have a large degree of deviation after entrance impeller channel because of the larger centrifugal force. The movement near the root of the blade pressure surface and impeller rear disk. Some particles collide the leading edge and the pressure surface of the blade near the wheel disc of the zone. Comparing with the particles with 50 μm diameter, the trajectories and flow lines of 100 μm particles have a more significant deviation, by the stronger centrifugal force, the movement of the particles close to surface pressure root and rear disc. The majorities of particles will collide the root of the blade pressure surface and impeller rear disc except blade leading edge. Especially in the blade of the exit, the particle motion is in close proximity to the blade surface, the frequency of collision is very high, while some particles collide the blade surface pressure again after the rebound, also collide the blade suction side. Frequent collisions of the particles and leaf blade generate serious erosion.

3.2 The erosive wear analysis of fan blade

This work investigated the erosion wear of centrifugal fan blade with the particle size of 20 μm and 100 μm respectively. The erosion of standard fan blade and bionic fan blade with particle diameter of 20 μm are shown in Fig. 10(a) and (b). Fig. 10(a) shows that the worn of standard fan blade mainly occurs in neutral position of the blade leading edge and near exit of pressure surface. The worn of the suction surface near the blade leading edge is mild. This phenomenon is corresponding with the trajectory of 20 μm particles. Fig. 10(b) shows that the worn position of bionic fan blade mainly occurs at the blade leading edge. The worn of the pressure surface of

the blade is mild and the worn area is smaller than the standard fan. In this simulation conditions, the erosion rate simulation results of standard fan blade and bionic fan blade are $9.42 \times 10^{-9} \text{ kg}/(\text{m}^2 \cdot \text{s})$ and $7.36 \times 10^{-9} \text{ kg}/(\text{m}^2 \cdot \text{s})$, respectively. The erosion rate of bionic blade is about 0.78% less than the standard blade.

The erosion of the standard fan blade and the bionic fan blade with the particle diameter of 100 μm are shown in Fig. 11(a) and (b). Fig. 11(a) shows that the worn of standard fan blade occurs mainly in blade root of the pressure surface near rear disk. The

Fig. 10 Contours of DPM erosion rate for a diameter of particle of 20 μm : (a) standard fan blade; (b) bionic fan blade

Fig. 11 Contours of DPM erosion rate for a diameter of particle of 100 μm : (a) standard fan blade; (b) bionic fan blade

most serious area of wear is close to exit. Fig. 11 (b) shows that the wear positions of two fan blades are roughly equal. The worn on the suction surface of the blade is mild, and almost no wear track occurs at the blade leading edge. This phenomenon is corresponding with the trajectory of $100\ \mu\text{m}$ particles. In this simulation conditions, the erosion rate simulation results of standard fan blade and bionic fan blade are $4.87 \times 10^{-7}\ \text{kg/m}^2 \cdot \text{s}^{-1}$ and $4.54 \times 10^{-6}\ \text{kg/m}^2 \cdot \text{s}^{-1}$, respectively. The erosion rate of bionic blade is more than the standard blade.

3.3 Simulation result discussion

3.3.1 Gas-phase flow analysis

Fig. 12 and Fig. 13 show the flow velocity contours (Fig. 12(a) and Fig. 13(a)) and flow path lines (Fig. 12(b) and Fig. 13(b)) of the surface region ($x=0$, cross section) of the two types blades, the standard fan blade and the bionic fan blade. As can be seen from the velocity contours, the flow velocities are higher around the surface of the standard fan blade than bionic fan blade. Especially in the groove channel, the flow velocity is significantly lower than

that of the standard fan blade. Compared to the bionic fan blade, it is showed that the flow path lines on the standard fan blade were smooth. But in the bionic fan blade, the groove surface has a greater influence on the airflow. The air is rotating in the groove channel, forming a stable low-speed reverse flow zone.

The special flow pattern in the groove has significant influence on the erosion resistance of the bionic fan blade. The rotating flow in the groove plays an air cushion effect. On the one hand, the grooves can enhance fluid turbulence, which lead to the change of the flow field around the groove surface, and the particle motion pattern is changed subsequently. Some of the particles will leave the surface along with air flow without impact, and these particles would impact the surface if the surface is smooth. Therefore, the number of the particles impacting on the surface is decreased. On the other hand, as a result of the decrease of flow velocity, the velocities of the particles in the two-phase flow are decreased as well. The rotating flow in the groove can absorb particle energy which used for impacting, and the energy used to impact is correspondingly reduced. These features all help to reduce the particle impact damage on the

Fig. 12 Flow velocity contours and path lines of the surface region of the standard fan blade: (a) flow velocity contours; (b) path lines

Fig. 13 Flow velocity contours and path lines of the surface region of the bionic fan blade: (a) flow velocity contours; (b) path lines

blade surface and reduce erosion wear.

3.3.2 Particles impact velocity analysis

The particle impact velocity is an important variable which influences the erosion behavior of materials. The dependence of erosion rate (E) on impact velocity (V_p) is expressed by the following equation:

$$E = kV_p^n \quad (16)$$

where n is velocity exponent and k is a constant. The velocity exponent is usually in the range of 2–3 for ductile materials, while for brittle materials, it can be much higher. Hence, it is clear that the erosion rate increases significantly with the increase of the impact velocity.

In the present work, the particle impact velocity distributing on the surface of the two types of blades were analyzed. The particle impact velocities were obtained by the FLUENT post-processing system. The impact velocities were recorded in the interval value of 2 units. Fig. 14(a) shows the impact velocity distribution on the blade surface. For the surface of the standard fan blade, the impact velocities are concentrated in 30 m/s. But for the surface of the bionic fan blade, the impact velocities are mostly concentrated in several fixed values, such as 10, 16 and 30 m/s. As a result, the particles impact on the

bionic fan blade surface occur at the lower impact velocities compared with the standard fan blade, which lead to a lower erosion than that of the standard fan blade.

3.3.3 Particle Impact Angle Analysis

Particle impact angle has an important effect on the erosion rate. The maximum erosion of ductile material occurs at impact angles between 20° – 30° ^[17]. The probability of the particle impact angle distribution on the blade surface is shown in Fig. 14(b). For the standard fan blade surface, all the impact angles are concentrated in 30° , and for the bionic fan blade surface, most of the impact angles fall in the range of 50° – 65° . Therefore, compared with the standard fan blade, the impacts on the bionic fan blade surface occurred at the high impact angles which lead to lower erosion. This is another reason that the bionic fan blade surface exhibits better erosion resistance.

3.3.4 Effect of the inject velocity on erosion

Fig. 15(a) shows the erosion rate dependence of the bionic and standard fan blades for different inject velocities at 30° inject angle. It is observed that the erosion rates of the bionic fan blade are lower than that of the standard fan blade at all particle injecting velocities studied in this paper. The erosion rates of two types of blades increase with the increasing

Fig. 14 Particle-surface impact velocity and angle distribution: (a) impact velocity; (b) impact angle

Fig. 15 Curves of erosion rate *vs.* inject velocity and particle diameter: (a) inject velocity; (b) particle diameter

inject velocity. The least-squares fit to the data points have been obtained by using the power law. It is observed that the erosion rate is exponentially related to particle velocity, which is in agreement with the relationship between the erosion rate and particle velocity as mentioned above.

3.3.5 Effect of particle size on erosion

Fig. 15(b) shows the relation between erosion rate and particle diameter of the bionic and the standard fan blade at 30° inject angle. It can be seen that the particles cause less erosion on the bionic fan blade than that of the standard fan blade. One can also see that the erosion rate changes steeply when the particle size is small (particle diameters are less than 100 μm), and the erosion rate changes smoothly when the particle size is larger than 100 μm . In the gas-solid two-phase flow field, the small particles tend to follow the flow path and are strongly influenced by flow turbulence, while larger particles tend to deviate considerably from streamlines and their trajectories are hard to be changed due to their important inertia.

4. Conclusions

In the present work, continuous-discrete phase models were used to predict the erosion of the standard and bionic fan blades. The positions of collision of the standard and bionic fan blades were discussed, and two kinds of centrifugal fan blade wear were compared. The effect of the particle diameter was studied by comparing the results, obtained by solving CFD problem. Conclusions are drawn as follows: the particles with the air flow into the impeller region from the current collector in axial direction, regardless of particle size, will make a 90° turn to enter the impeller channel. the particles from the incident source with different positions have different processes of turning and movement when they enter into impeller. Some particles can directly enter the impeller channel from the current collector into the impeller region. Some particles will enter the impeller channel after rotating with the flow in the importing region of the blades. The trajectories of flow in the fan channel are significantly different for the particles with different diameters.

The comparison results of the bionic fan blade and standard fan blades show that the bionic fan blade have lower erosive wear rate than the standard fan blade when the particle size is 20 μm , but the result is opposite when the particle size is 100 μm .

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REFERENCES

- [1] M. Sharma, J. Bijwe, K. Singh and P. Mitschang, *Wear* **270** (2011) 791.
- [2] P.S. Babu, B. Basu and G. Sundararajan, *Wear* **270** (2011) 903.
- [3] Y.F. Wang and Z.G. Yang, *Wear* **265** (2008) 871.
- [4] Y.T. Xi, D.X. Liu, D. Han and Z.F. Han, *Acta Metall. Sin. (Engl. Lett.)* **21** (2008) 21.
- [5] A. Krella, *Wear* **270** (2011) 252.
- [6] P. Sampathkumaran, C. Ranganathaiah, S. Seetharamu and Kishore, *Int. J. Adv. Manuf. Technol.* **52** (2011) 45.
- [7] X.F. Yang, M.S. Chu, F.M. Shen and Z.M. Zhang, *Acta Metall. Sin. (Engl. Lett.)* **22** (2009) 454.
- [8] S.F. Zhu, Y.C. Wu and X.M. Huang, *Asian J. Chem.* **23** (2011) 2299.
- [9] G.C. Saha, T.I. Khan and G.A. Zhang, *Corros. Sci.* **53** (2011) 2106.
- [10] M. Suzuki, K. Inaba and M. Yamamoto, *J. Therm. Sci.* **17** (2008) 125.
- [11] V. Bonache, M.D. Salvador, J.C. Garcia, E. Sanchez and E. Bannier, *J. Therm. Spray Technol.* **20** (2011) 549.
- [12] B.S. Mann, V. Arya and B.K. Pant, *J. Mater. Eng. Perform.* **20** (2011) 213.
- [13] X.B. Zhang, C.S. Liu, X.D. Liu, J. Dong and B. Yu, *Int. J. Miner. Metall. Mater.* **16** (2009) 203.
- [14] Z.W. Han, J.Q. Zhang, C. Ge, J.L. Jiang and L.Q. Ren, *J. Wuhan Univ. Technol.* **26** (2011) 306.
- [15] Z.W. Han, J.Q. Zhang, C. Ge, Y. Lü, J.L. Jiang, Q.P. Liu and L.Q. Ren, *J. Bio. Eng.* **7** (2010) S50.
- [16] L.Q. Ren and Y.H. Liang, *Sci. China: Ser. E* **52** (2009) 2791.
- [17] Z.W. Han, J.Q. Zhang, C. Ge, W. Li and L.Q. Ren, *Langmuir* **28** (2012) 2914.
- [18] A.C. Amezcua, A.G. Munoz, C.A. Romero, Z.M. Czerwicz and R. C. Amezcua, *Appl. Therm. Eng.* **27** (2007) 2394.
- [19] A.A. Hamed, W. Tabakoff, R.B. Rivir, K. Das and P. Arora, *J. Turbomach.* **127** (2005) 445.
- [20] A. Hamed, W. Tabakoff and R. Wenglarz, *J. Propul. Power.* **22** (2006) 350.