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Production of Stainless Steel Fiber by Machining for Reinforced Refractories

切削による耐火物補強用ステンレススチールファイバーの製造

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1. Introduction

A Refractories for the furnace always receives a cyclic thermal stress, which causes cracking of the furnace and shortens its life. However, the castable furnace material, in which thermo-stable aggregate is mixed with cement, is able to increase its strength against the thermal stress by mixing the fiber into the cement just like the Steel Fiber Reinforced Concrete. In case of the furnace, stainless steel must be used for reinforcement due to its high heat resistance. It is known that a mixture of the stainless steel fiber into the castable refractories gives an excellent efficiency of the reinforcement.

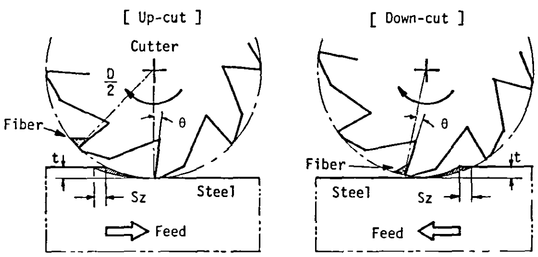

Fig. 1 Schematic principle of production of fibers by a milling machine

The stainless steel fiber has been produced by the shearing of thin sheet or the melt−extraction method. This investigation was aimed to obtain the stainless steel fiber with better quality at lower cost by the newly developed production process using machining which has been successfully applied to the steel fiber for concrete.

2. Experimental procedure of making the machined fiber

Fig. 1 shows the production principle of the fiber by using milling machine and Table 1 indicates the machining condition for fiber production which is nearly the same as the steel fiber reported before. Work material is hot rolled 18Cr-8Ni stainless steel sheet with 30mm thickness which corresponds to the length of the fiber. A plain milling cutter is made of cemented carbide and cutting was carried out without cooling oil.

3. Results and discussions

Among the fiber characteristics, the geometry and the strength seems to be very important. In this paper the effect of cutting conditions on these were experimentally investigated.

Table 1 Experimental machining conditions of the production for stainless steel fiber

Employed machine	Horizontal type milling Machine (No.3, 5Kw, arbor diameter− 1 1/2")
Cutter	A plane milling cutter (cemented carbide) D = ϕ100mm twist angle : α=15° Radial rake angle θ =−15°, −5°, 5°, z = 5, 10
Material	18Cr−8Ni Stainless steel t = 30mm, σ_B = 66·8 kg/mm²
Cutting Conditions	Dry cutting V = 24, 116 m/min

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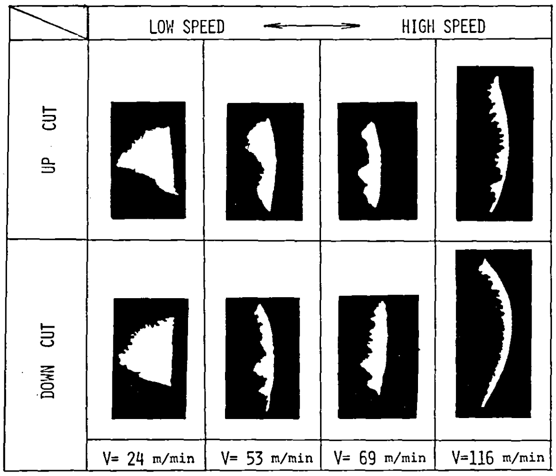

Fig. 2　Effect of tne cutting speed on the cross sectional geomerty of fibers (18−8 Stainless steel, Sz≒0.4mm, t＝0.4mm, α＝15°, θ＝−15°, D＝ϕ100mm)

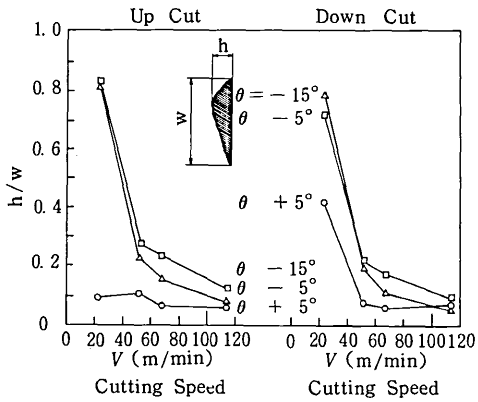

Fig. 3　Effect of the cutting speed on the cross sectional geometry of fibers (18 − 8 Stainless steel, Sz≒0.4mm, t＝0.4mm, α＝15°, D＝ϕ100mm)

3.1　Cross sectional geometry

a) Effect of cutting conditions

Fig. 2 shows the cross–sectional geometries obtained in two different cutting directions such as up-cut and down-cut as illustrated in Fig. 1. The cross-sectional areas are equally 0.16mm² in all cases in the figure, which are determined by the depth of cut t and the feed of a tooth Sz. The geometry of cross -section is not so influenced by the difference of cutting directions as it was in steel fiber. From the view of tool life, however, dowh- cut is known to be more preferable.

b) Effect of cutting speed

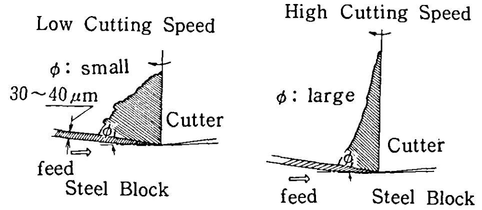

Fig. 4　Effect of the cutting speed on the shear angle ϕ (D＝ϕ100mm, θ＝0°)

Cutting speed gives a marked influence on the geometry as shown in Fig. 2. The fiber with thick triangle section is produced at a cutting speed of 24m/min, while at 116m/min the fiber with very thin crescent section is obtained. Fig. 3 shows the relation between cutting speed and thickness width ratio h/w of fiber section. The thickness of fiber section, becomes thinner with an increase of the cutting speed. This effect can be explained by the changes of shear angle ϕ at low and high speed cutting as shown in Fig. 4.

c) Effect of rake angle

Fig. 5 and 6 show the cross section geometry at different rake angles. The shapes of section become thinner with an increase of the rake angle, which can be also explained as the increase of shear angle. The cutting speed, however, gives stronger influence on the geometry than the rake angle. An optimum value of rake angle, in actual production is supposed to be negative in order to prevent the chipping of cutting teeth.

3.2　Surface of the fiber

Fig. 7 shows the appearances of typical two kinds of stainless fiber produd at defferent cutting speed.

The fiber below produced at lower cutting speed has a triangle section as illustrated in Fig. 2, and has a ragged surface because of the slightly unstable cutting condition. In addition, this fiber is less twisted in longitudinal direction. Only from the appearance, this is similar to the sheared fiber form thin sheet which is widely used.

On the other hand, the fiber above produced at higher cutting speed shows the form of a twisted foil. Such twisted foil fiber is expected to have not only an excellent adhesion to the matrix material through its wide surface area but also a good mixability with the concrete matrix due to its

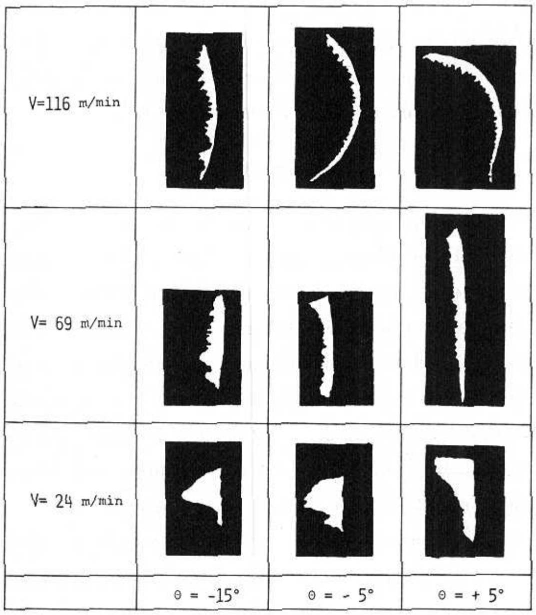

Fig. 5 Effect of the rake angle on the cross－sectional geometry of fibers
(18－8 Stainless steel, Sz ≒ 0.4 mm, t = 0.4 mm, Down-cut, α = 15°, D = ϕ 100 mm)

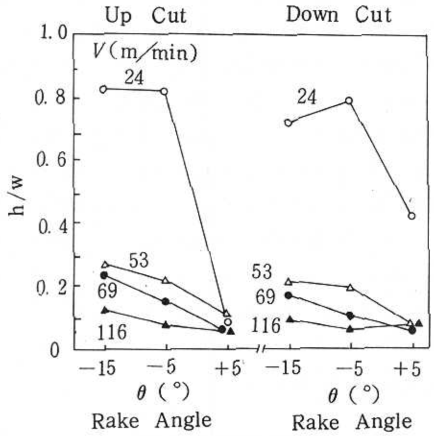

Fig. 6 Effect of the rake angle on the cross sectional geometry of fibers
(18 － 8 Stainless steel, Sz ≒ 0.4 mm, t = 0.4mm, α = 15°, D = ϕ 100mm)

flexibility in bending.

Fig. 8 represents enlarged surface appearance of foil fiber by the scanning electro micro photograph. This surface is the opposed side of the raked side which contacts with tool at the time of cutting. These fine ragged marks running in the longitudinal direction of the fiber, corresponding

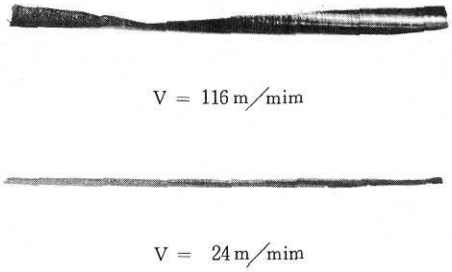

Fig. 7 Effect of the cutting speed on the appearances of the fiber
(18－8 Stainless steel, Sz ≒ 0.4mm, t = 0.4mm, Down-cut, α = 15°, θ = － 15°; D = ϕ 100mm)

with ragged surface as shown in Fig. 3 seems to increase both an adhesion to the matrix and a resistance to pull out from it as well as to make the surface area wider.

3.3 Strength

a) Effect of cutting speed

Fig.10 shows the relation between the tensile strength of fibers and the cutting speed, where the tensile strength decreases with an increase of cutting speed. At a lower cutting speed can the fiber with over 100 kg/mm^2 in strength be obtained, but 60－70 kg/mm^2 in strength can be done at a higher cutting speed. This tendency is completely contrary to the case of the steel fiber. Though deeper investigation is neccessary to make it clear what it takes place, following two reasons are considered to explain for the tendency. Firstly, at a higer cutting speed a work hardening occurs

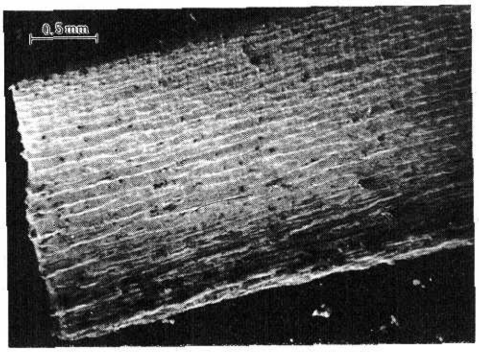

Fig. 8 Scanning electro micrograph of the stainless steel fiber
(18 － 8 Stainless steel, V = 116m/min, Sz ≒ 0.4mm, t = 0.4mm, Down-cut, α = 15°, θ = － 15°, D = ϕ 100mm)

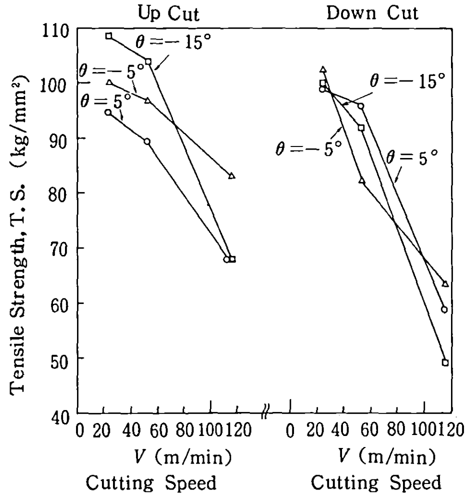

Fig. 9　Effect of the cutting speed on the strength of fibers
(18 − 8 Stainless steel, Sz ≒ 0.4 mm, t = 0.4 mm, $\alpha = 15°$, D = ϕ100 mm)

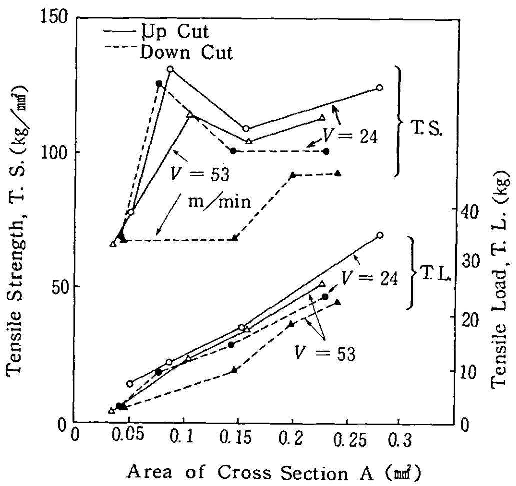

Fig. 10　Effect of the area of cross-section on the strength of fibers
(18 − 8 Stainless steel, $\alpha = 15°$, $\theta = -15°$, D = ϕ100 mm)

to a less extent due to smaller strain with bigger shear angle. The thin fiber such as the twisted foil shaped fiber outwardly decreases in strength since it is easy to be broken off unnaturaly at the edge and surface or notches of the twisting parts. However, the value of 60 − 70 kg/mm² at twisted foil shaped fiber in strength is quite enough to be applied for the furnace.

b) Effect of cross sectional area

The machining method has a feature of being able to easily produce the fiber whose cross-sectional area is quite small. Fig. 10 represents the relation between the tensile strength and the cross-sectional area. Even the smallest one, 0.04 mm² in cross-sectional area, has a sufficient strength such as 70 kg/mm².

4. Conclusions

a) Not only the fiber being similar to the existing fiber of which cross-sectional shape is a thick triangle, but also the twisted foil shaped fiber can be produced by this method. This twisted foil shaped fiber is supposed to provide with an excellent adhesion originated from its large and rugged surface area. Further this fiber can be produced at high productivity because foil shape can be obtained at higher cutting speed.

b) The very fine fiber whose cross-ectional area is only 0.04 mm², one sixth of the commercial fiber, can be easily produced.

c) In actual cutting conditions, down-cut milling should be chosen for the purpose of increasing the tool life, and the cutter with a negative rake angle is suitable to be applied for the sake of the prevention against chipping of the tools.

d) The fiber becomes thinner in the cross-sectional shape and is lowered in strength with increasing the cutter speed. The foil fiber produced at a higher cutting speed is supposed to have sufficient strength for reinforcement. Therefore the fiber produced at a higher cutting speed is more preferable from a view point of higher productivity and more stable cutting, unless the fiber is exceptionally necessary whose cross-sectional shape is a thick triangle.

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