SURFACE QUALITY IN THE GRINDING OF STAINLESS STEELS (2nd Report) —Effects of Number of Pass Times of Grinding in Surface Grinding on the Surface Qualities of the Works—

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Abstract

The CBN abrasive wheel has recently been used in practice as a beneficial wheel from the standpoint of surface qualities.

In this report, surface grinding experiments were carried out with stainless steels using alumina, silicon–carbide and CBN wheels.

The effects of (1) the number of pass times of grinding, (2) the types of wheel, and (3) the work materials on the affected layers, and on the ground surface roughness and, finally, on the grinding forces were examined. And, then, the degrees of work hardening or the thermal influences on the constrained and unconstrained works were explored in order to examine the effects of the conditions of constraint of working stress on surface qualities.

Of all types of wheels employed, the CBN wheel showed excellent results in the affected layer and in the grinding forces except in the area of surface roughness.

1. Introduction

In previous report[1)] surface qualities of stainless steels (SUS 304, SUS 403, SUS 440C)ground with 19A, GC and CBN abrasive wheels were compared with each other in one pass grinding, and it was shown that CBN abrasive wheel obtains good results for the affected layer of small size work and hardened steel especially.

It was expected in that report that the differences in the condition of stress constraint in grinding are occured according to the sizes of the works and the condition of work holding.

However, because of that the test was carried out one pass grinding in that report, it seems to be not usual for practical. So, in this report giving the depth of cut of 10 μm at evety pass and varing the number of pass times 3, 5, 7 and 10 times, tests were carried out in surface grinding.

And moreover, the effects on the affected layer are also discussed on the cases that made severe the constraint conditions of working stress due to grinding forces by using the constraint holder for the work.

2. Test conditions

Tests were carried out as shown in Table 1, at constant table speed f = 5m/min and giving the depth of cut $\triangle = 10\mu$m at the right and left end of the work respectively in every pass.

The number of grinding pass time 3, 5, 7 and 10 times were tested on each test piece. Grinding forces (Ft ; tangential, Fn ; normal) and actual depth of cut were measured at each one pass, and mean measurement values were adopted at every pass. More, the variations of hardness of work material and microphotographs are ones after grinding pass 3, 5, 7 and 10 times respectively. The other test conditions are omitted because same as in 1st report.

Table 1 Test conditions

Grinding machine	Surface grinder PSG-3A-D 0.75 KW
Grinding wheel	A) 19A180KV75R $^{\phi}200 \times {}^{\phi}38.1 \times 19$ B) GC180KV81R C) CBC170N75BW4 $^{\phi}200 \times {}^{\phi}38.1 \times 20^{T} \times 3^{X} \times 10^{L}$
Work material	1) SUS 304 2) SUS 403 3) SUS 440C height width length 45×15×40mm Heat treatment; same as 1st report
Grinding condition	Wheel speed V m/min 2300 Table speed f 〃 5 Depth of cut/one pass Δ μm 10 Pass times of grinding 3, 5, 7, 10 Cut without spark-out
Coolant	Emulsion (for CBN wheel) 5 % solution (for 19A, GC wheel) 1.25% 4 l/min

3. Experimental results and discussions.

3.1 Variations in hardness of work material

3.1.1 Effects of types of abrasive wheel

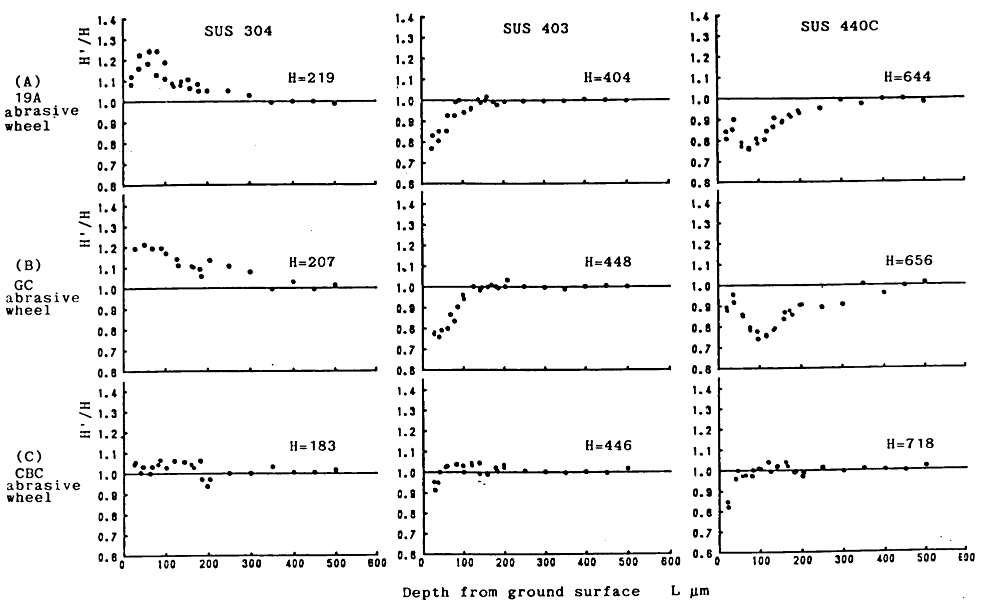

Fig. 1 Variation in hardness of work material (on grinding pass time n=5) △=10μm/pass f=5 m/min

Fig. 1 shows the vatiations in hardness of work material measured in vertical cross section to ground surface on the case of 5 times grinding passes. The distributions of hardness from ground surface to bottom of work are shown as the hardness ratio H'/H, where H and H' are Vicker's hardness of base metal and affected layer respectively.

For all the work materials SUS 304, SUS 403 and SUS 440C, CBN abrasive wheel (C, in same figure) shows that the degrees of annealing or tempering due to grinding and of the work hardening due to grinding force in the grinding surface layer are small compared with 19A (A, in same figure) and GC abrasive wheel (B, in same figure). Accordingly, it is evident that CBN abrasive wheel does not affect thermal and stress influences on the ground surface layer compared with the otheres: 19A and GC abrasive wheel develop annealed layer in the surface by grinding heat for SUS 304 had a remarkable work hardenablity, and for SUS 403 and SUS 440C hardened material develop tempered layer or re—hardened layer, while, CBN abrasive wheel does not shows those tendencies or even if they were shown those tendencies it's degree is small. This is due to the characteristics of CBN abrasive particle with higher heat conductivity.

3.1.2 Effects of number of grinding pass time

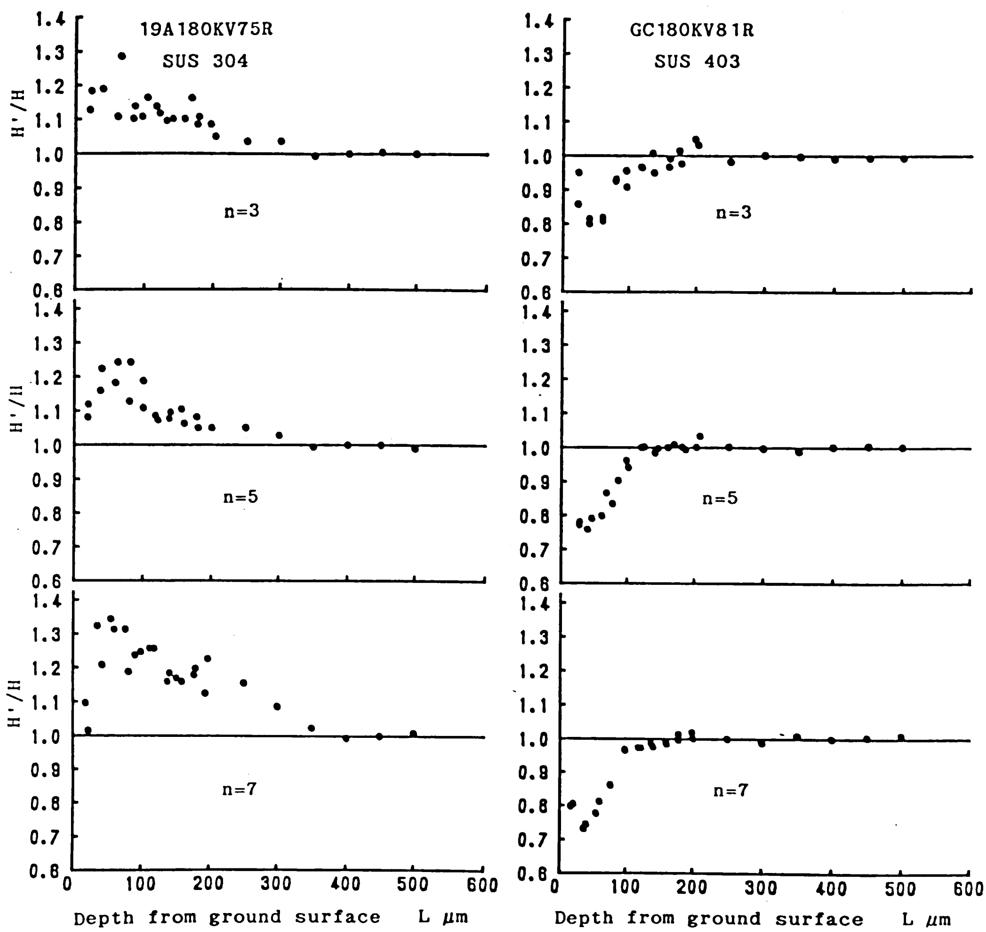

Fig. 2 Variations in hardness of work material (on effects of grinding pass time)

It is considered that the effects on the affected layer are to be accumulate when repeat the grinding pass giving the depth of cut at every pass without spark—out.

Fig.2 is an example examined the effects of the number of grinding pass time n on the affected layer by the distributions of hardness ratio H′/H, on the case of 19A abrasive wheel for SUS 304 and GC abrasive wheel for SUS 403.

It is obvious from the figure that the degree of work hardening in SUS 304 due to working stress and in SUS 403 the degree of annealing due to grinding heat, both increase with the increase of number of grinding pass time n.

In CBN abrasive wheel these tendencies as in 19A and GC wheel were not clearly seen and not affected by n in every material adopted, therefore difficult to see the states of affected layer with increasing of n. It is obvious to depend on the characteristics of CBN abrasive particle. It is considered that CBN particle characteristics of excellent heat conductivity, higher hardness and toughness are caused.

Now, to make futher clear these, Fig.3 is shown. —A qualitative tendency shown the degree of thermal effects and of the work hardening obtained by applying the procedure of Mizutani and Nakajima [2] is shown—In same figure S_1 shows the any scale shown the degree of thermal effect due to re—hardening, S_2 the degree of tempering and S_3 the degree of work hardening. As obvious from the figure, SUS 304 (A) had a high work hardenability is shown by only S_3 which shows a work hardening layer in all abrasive wheels. CBN wheel shows the smallest effects compared with 19A and GC wheels. The degrees of work hardening increase with the increase of n in both 19A and GC wheels, but in CBN wheel, the degree is smaller than other wheels and the relation between n and S_3 cannot clear.

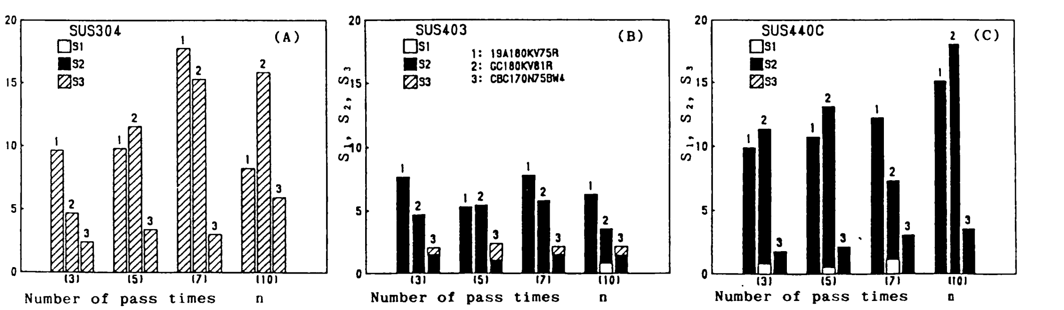

Fig. 3 Evaluation of the degrees of heat and stress effects in the affected layer shown by any scales S_1, S_2, S_3

In same figure (B) of hardened steel SUS 403, the most of affected layer show S_2 that is a tempered layer due to grinding heat, on the other hand, CBN wheel shows little effects of grinding heat, the degree is small and subjected rather the work hardening in part. So, it can be considered that the temperature of ground surface with CBN wheel was considerably low.

In same figure (C) of SUS 440C, the degrees of tempering are greater than the case (B) SUS 403. This seems to be sensitive for tempering because of high hardeness of this material compared with SUS 403. In this case also the thermal effects of CBN wheel on ground surface are very small.

In any case, the degrees of thermal and working stress effects of CBN wheel on ground surface are smaller than the other wheels examined.

3.2 Microstructure of affected layer

Fig.4 is an example showing the effects of number of grinding pass time n on affected layer using S.E.M.

With the increase of n as seen from (A) to (C) in same figure, in SUS 304 with 19A abrasive wheel, the variation in the degree of work hardening is observed on the microstrucuture, TWIN" is observed on the case 7 times (C). So, it is considered to be subjected fairly highly working stress.

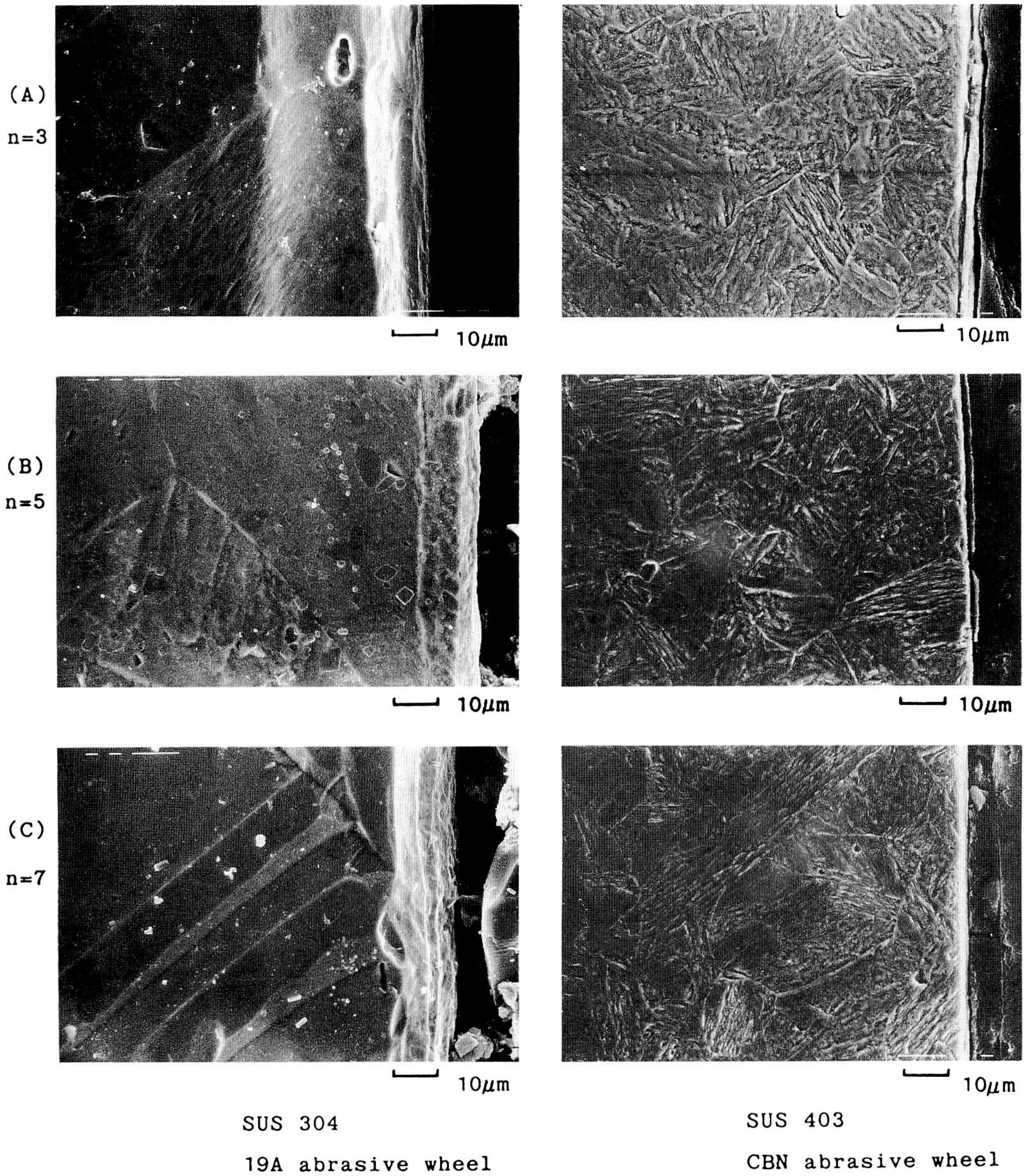

Fig. 4 Microstructure of damaged layer ground with 19A and CBN abrasive wheel (on effects of grinding pass times n)

On the other hand, in SUS 403 with CBN abrasive wheel as same as mentioned above 3.1, there is little obvious variation in the microstructure with the increase of n.

3.3 Grinding force

3.3.1 Tangential and normal grinding forces Ft, Fn.

The relations between grinding forces and number of grinding pass times n are shown in Fig.5. Each force is shown by mean values per one pass on each pass and per unit width of work.

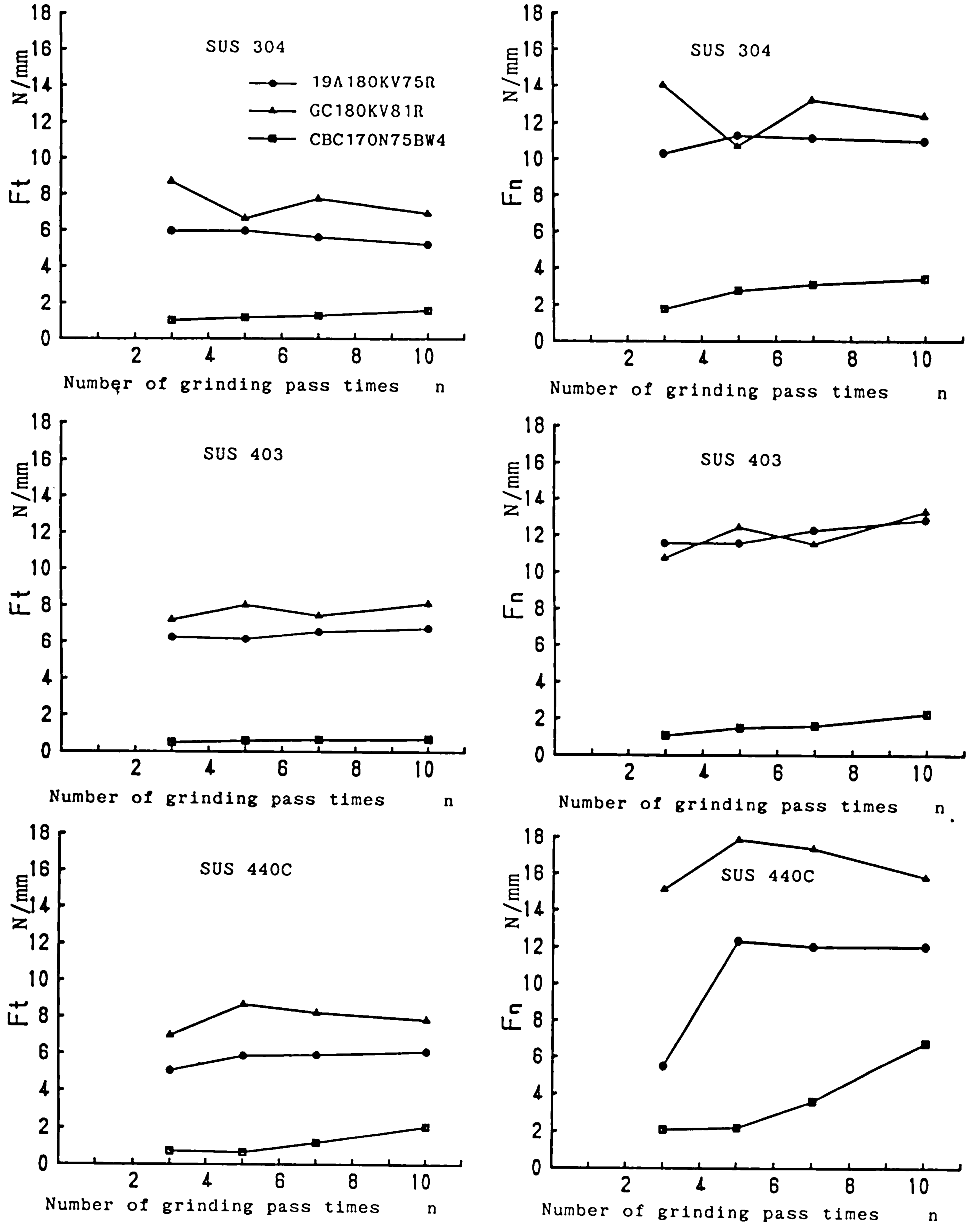

Fig. 5 Relation between grinding forces and number of grinding pass times

The grinding forces become small in order GC, 19A, CBN abrasive wheels, especially the forces by CBN wheel are very small among of them.

Among of 3 types stainless steels, in SUS 304 and SUS 403 relatively softer material, grinding forces increase with the increase of n together with 3 types abrasive wheel, but in hardest SUS 440C, with 19A and GC wheels, the forces begin to decrease on about n = 5 times, while in CBN wheel the forces rather increase with the increase of n especially in Fn. It is evident from the differences among of each abrasive, that is, each abrasive particle has a characteristics to suit for each material respectively.

3.3.2 Grinding force ratio Ft/Fn

Fig.6 shows the ratio Ft/Fn of tangential (Ft) and normal (Fn) grinding forces of 3 types of abrasive wheel for the work materials, as the mean values over the all cases for every work material.

GC abrasive wheel shows largest ratio and CBN wheel shows smallest ratio of 3 types wheel for every work material, that is, the ratios are in the order of the brittlness of abrasive particles of 3 types of wheel.

Now, if consider the ratio Ft/Fn apparent coefficient of friction μ between wheel and ground surfacem, it may be explained as follow that the irregularties of abrasive grain protrusion from wheel surface are decreased and flattened with repeating the pass grinding giving the depth of cut at evety pass. So, the number of abrasive particles subjected to cut at same time increases, then frictional resistance increases. This is also obvious from tangential forces in Fig. 5.

3.4 Metal removal rate and surface roughness

Fig.7 shows the ratios actual metal removal rate q_{act} to theoretical one q_{th} with mean values the all of number of grinding pass time on each material. As a matter of course the differences shall be caused in the metal removal rates according to the toughness, hardness of abrasive particles themselves and the grades of the abrasive wheels etc, owing to repeating the grinding pass without spark—out.

In this test however, the obvious differences are not caused probably because of that the depth of cut was relatively small at 10 μm and maximum number of grinding pass time n was also small at 10 times, and moreover, because of that the varieties of actual depth of cut by elastic deformation due to grinding forces or of thermal expansion of work materials due to the differences of each abrasive's thermal conductivity. Only, it is seen that CBN wheel shows slightly good performance in SUS 440C hardened material.

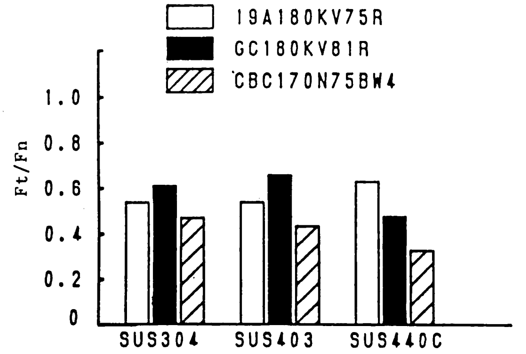

Fig. 6 Comparison of Ft/Fn

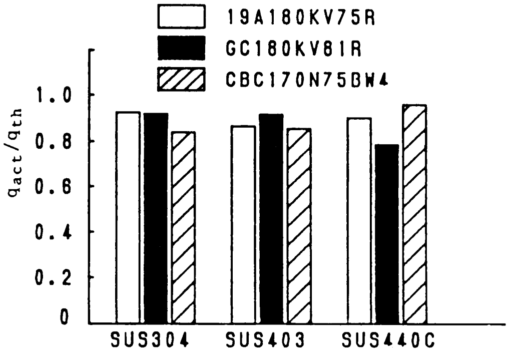

Fig. 7 Comparision of q_{act}/q_{th}

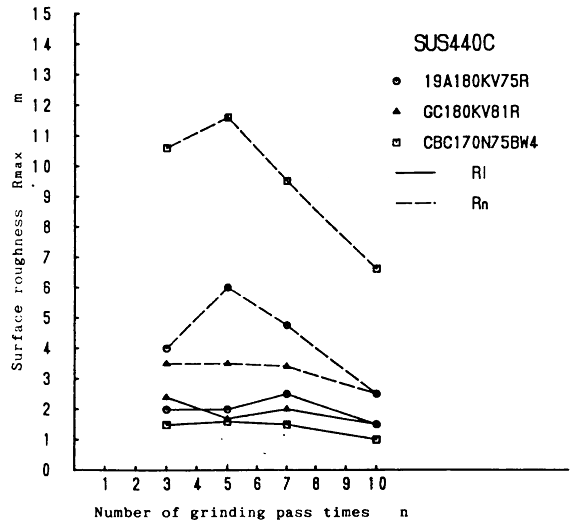

Fig. 8 Variations of surface roughness

It is considered for grinding surface that the toughness or hardness of abrasive particle and the grade of bond of wheel etc affect complexly on, and repeating the grinding pass n improves surface roughness.

Though it cannot been obtained the obvious qualitative relations between n and surface roughness, the results as shwn in Fig. 8 were obtained in SUS 440C hardest material. Rl and Rn are surface roughness along to and across to the grinding direction respectively.

The surface roughness of across direction Rn is larger than that of grinding direction Rl in every wheel.

The surface roughness Rl and Rn decrease with n increases.

In CBN wheel Rn decreases rapidly as exceeds n = 5, in 19A wheel though the degree is small shows also similar tendency, and in GC wheel that tendency is smallest.

The Rn values become small in the order of the brittleness of abrasive particles, that is, the values of Rn are largest in CBN, then in 19A and in GC wheel the values of Rn are smallest. The values of Rn are improved in the order of the brittleness of abrasive particles. On the other hand the values of Rl the roughness along to grinding direction are not like so, rather improved with the CBN wheel that the toughness of abrasive is highest of 3 types of the wheel employed.

In surface grinding without cross feeding of table, the irregularities of wheel surface become to be copied, as they are, on the ground surface as a roughness across to grinding direction. Therefore the condition of wheel surface is important.

However, in the surface roughness along to grinding direction it's generation mechanisms are complex, the slippings of abrasive particles, the remainings not beeing cut and number of cutting edges acting at same time, or thermal expansion of works etc linking together complexly give a complicated generated surface on ground surface. Accordingly, the roughness along to grinding direction is not alway in the order of the brittleness of abrasive particles as in the case of roughness across to grinding direction.

Fig. 9 is the comparison of Rl and Rn, where the values of Rl and Rn, are the mean values in the

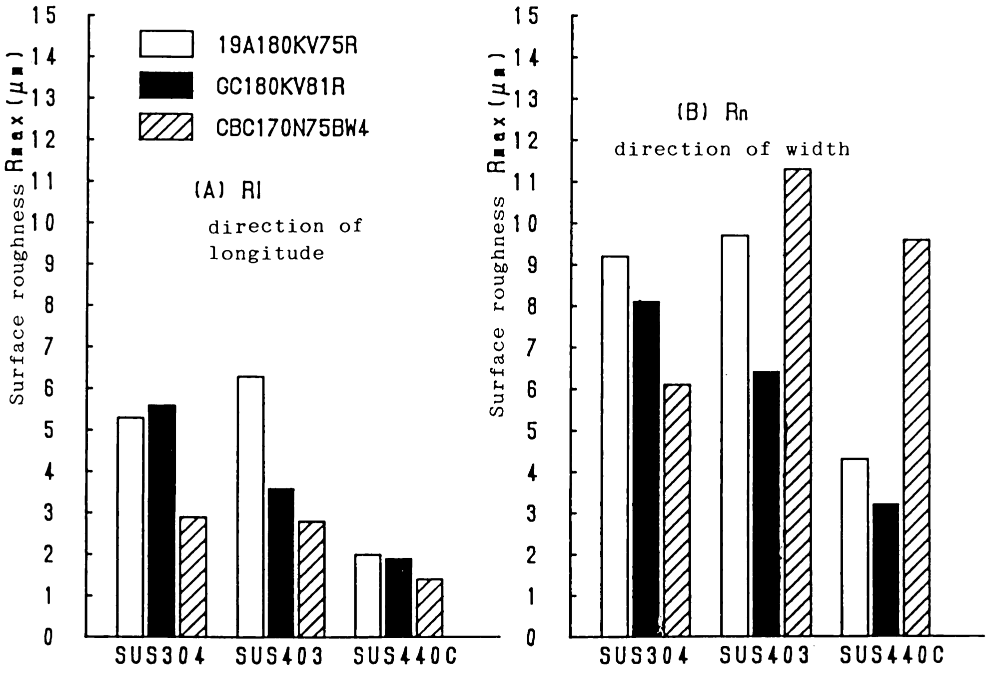

Fig. 9 Comparison of surface roughness

all of grinding pass on each work marerial.

It is seen that in same figure (A) roughness R1 are smallest with CBN wheel for every material, on the contrary in (B), roughness Rn is on the whole greater than in R1. Especially in SUS 403 and SUS 440C comparative hard material the values of Rn with CBN are lager, as mentioned above this is dependent on the toughness of each abrasive particles.

3.5 Effects of the conditions of the mounting of work to work holder on affected layer.

In the 1st report it was pointed out that small size work makes the constraint conditions of working stress less strong because of easy elastic deformation due to grinding forces, and so, in SUS 304 had a higher degree of work hardenability the degree of work hardening becomes small, then the effects on affected layer also vary, and that the size effects of the works exist for the affected layer as a matter of course not only in SUS 304 but in the other materials.

The differences of the effects on affected layer between constrained and unconstrained works are examined with the work holder as shown in Fig. 10. Using this holder the elastic defomation of work difficult to occur.

Fig. 11 shows an example of grinding forces on the cases of constrained and unconstrained of work. Obviously the grinding forces (Ft : tangential, Fn ; normal) of constrained work are larger than unconstrained ones.

Fig. 12 shows the microstructure with S. E. M. of the works of constrained and unconstrained in SUS 304. Plastic flow are seen at surface layer in constrained (A) and not seen in unconstrained (B). It is seen obviously that the work constrained subjects larger working stress than unconstrained one.

Fig. 13 shows the variations of hardness in work material in SUS 304 ground at 40 μm of depth of cut and at one pass, on the unconstrained and constrained work. It is obviously seen that the degrees of the work hardening of constrained work are larger than that of unconstrained work, althogh

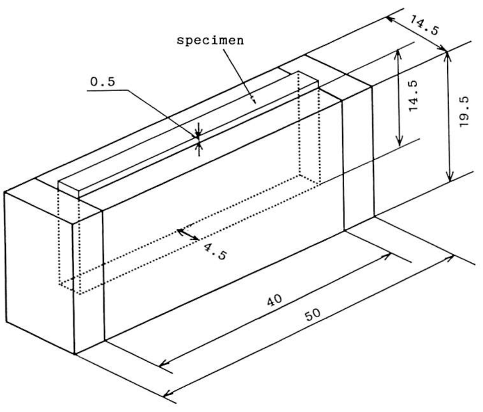

Fig. 10 Specimen holder for constraint

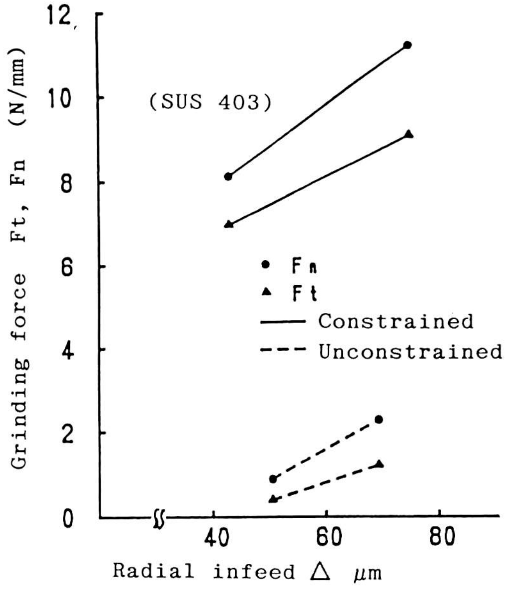

Fig. 11 Comparison of grinding force at the condition of constrained and unconstrained.

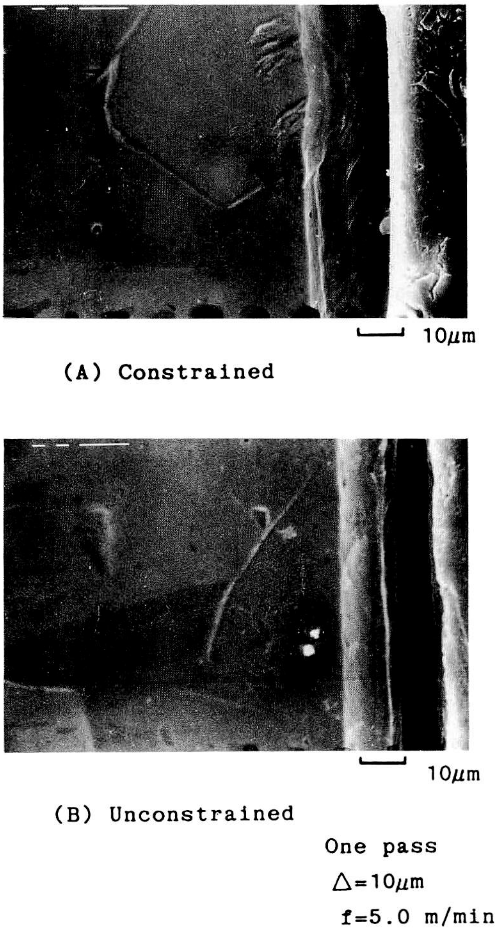

Fig. 12 Microstructure of SUS 304 ground with CBN abrasive wheel

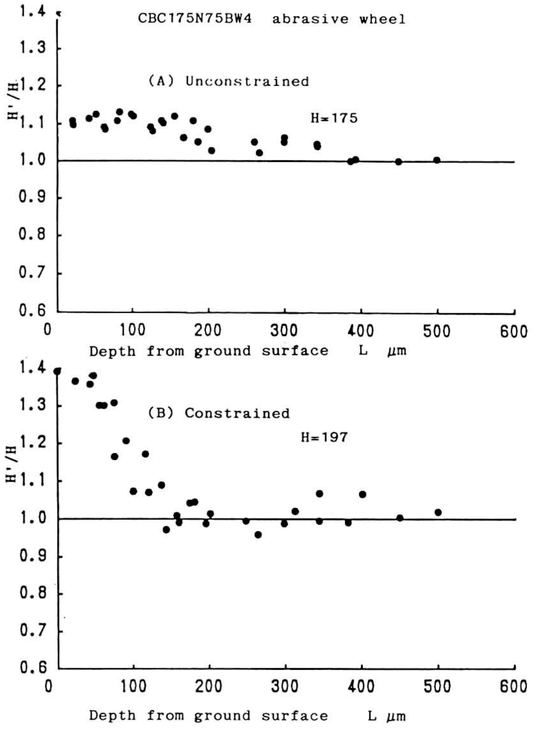

Fig. 13 Comparison of the hardness of work material between constrained and unconstrained specimen (SUS 304, $\triangle=40\mu m$)

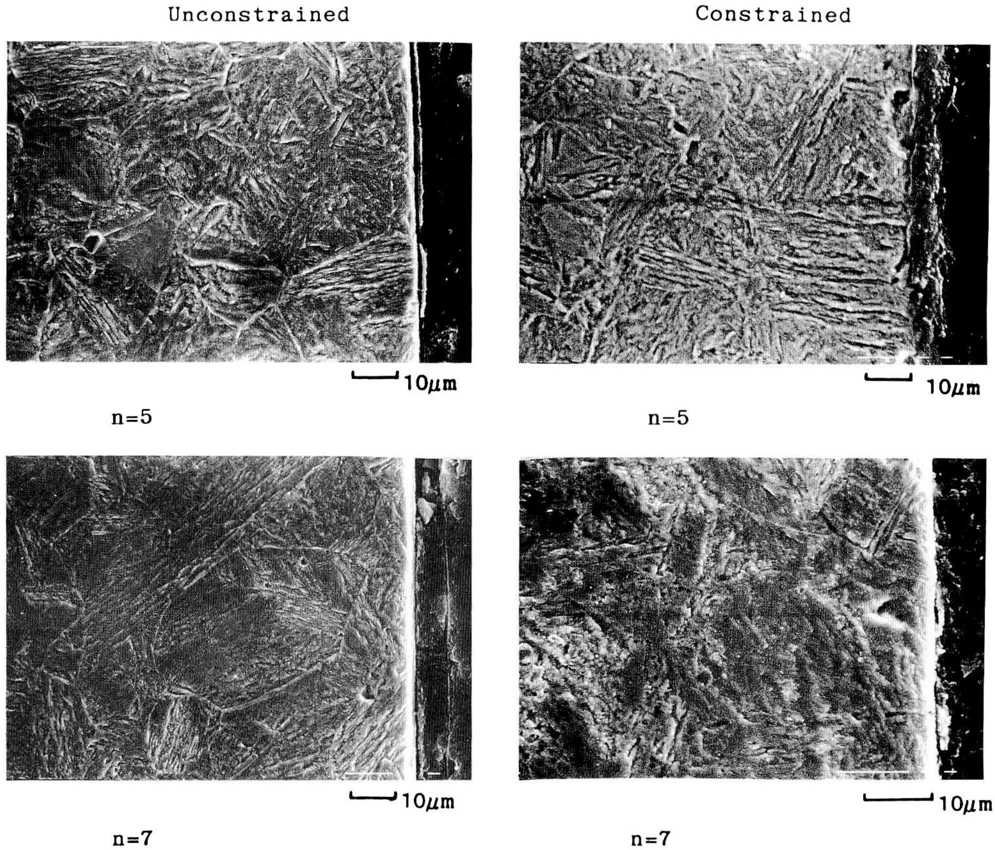

Fig. 14 Microstructure of SUS 403 ground with CBN abrasive wheel $\triangle = 10\mu m$, f=5.0m/min

the depth of affected layer not so varies.

Fig. 14 shows the microstruture with S.E.M. on about n=5 and 7 times, ground by CBN wheel for SUS 403. There are not so much differences as in SUS 304 shown in Fig. 12, this will may be due to the differences whether the material is sensible to working stress or to temperature.

4. Conclusions

The effects of the types of abrasive wheel and of the number of pass time of grinding on surface-qualities in surface grinding of stainless steels SUS 304, SUS 403 and SUS 440C, were examined, and then on the case of unconstrained and constrained works, the degrees of effects on affected layer and grinding forces are also examined.

The results obtained are as follow.

1. The effects on affected layer are small in CBN abrasive wheel compared with 19A and GC wheels, especially thermal effects are very small, even if repeat the grinding without spark–out giving the depth of cut.
2. The ground surface roughness across to grinding direction by CBN abrasive wheel is larger than the other 19A and GC wheels. However, the one along to grinding direction by CBN abrasive wheel

is smaller than the other 19A and GC wheel.

3. When small size works are ground constraining the elastic deformation, the affected layer of material had easy work hardenability is affected by working stress largely.
4. Therefore, it is expected that the work's size effects for the affected layer by work hardening are existed.

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