High Accurate Hobbing With Specially Designed Finishing Hobs

Yasutune Ariura and Yoji Umezaki

Introduction

Load-carrying capacity of gears, especially the surface durability, is influenced by their tooth surface roughness in addition to their tooth profiles and tooth traces (Refs. 1 and 2). The harder the gears are, the smoother their tooth surfaces and the more accurately their tooth profiles should be finished in order to obtain high load-carrying capacity. Through research, the relationship between the cutting thickness (undeformed chip thickness), the size of built-up edge (BUE) and the tooth surface roughness has clarified that the number of gashes and the rake angle in hobs has an effect on the cutting thickness and the BUE formation, respectively. The cermet-tipped hobs developed by Ariura and Umezaki (Ref. 4) have excellent cutting performance with respect to wear resistance, tooth accuracy of hobbed gears and roughness of their tooth surfaces for gear blanks with hardness up to about 400HBW.

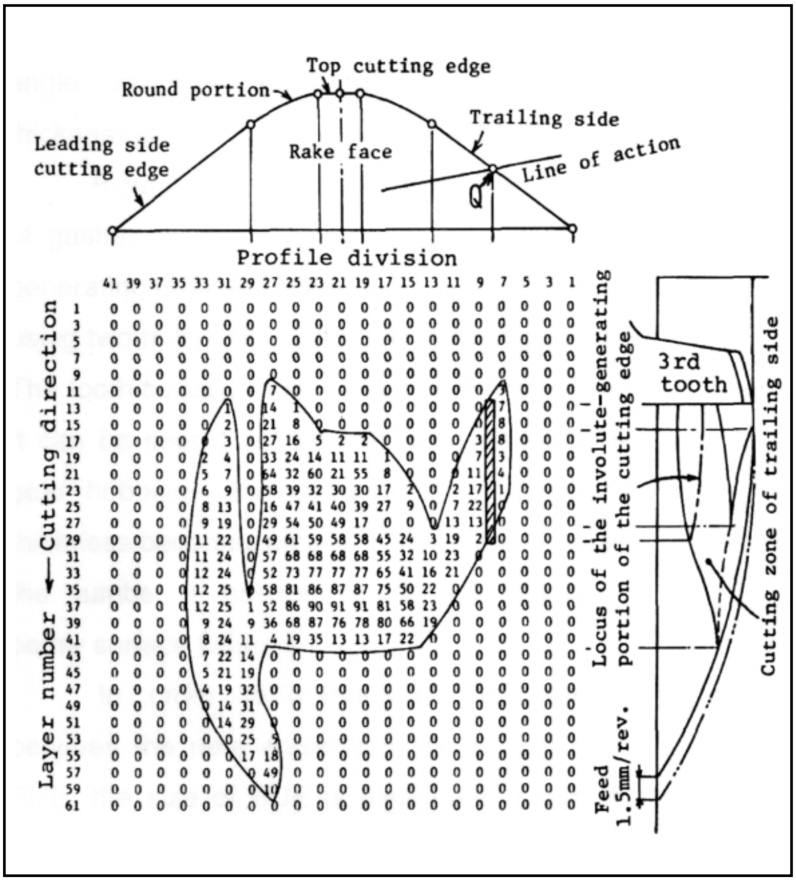


Figure 1—An example of calculation of undeformed chip thickness (Ref. 9).

For surface hardened gears (550N–800HV), some method of appropriate surface finishing is necessary for removing their distortion after heat treatment. One finishing method is skive hobbing with cemented carbide hobs, as shown by Yonekura and Ainoura (Ref. 5). However, most other finishing methods involve tooth grinding and honing (Refs. 6, 7, and 8).

In this article, the optimal finishing is investigated from a point of view of economy and productivity. This article presents finishing hobs, which are different from skiving hobs. In finishing hobs, the following characteristics are required: (1) good wear and chipping resistance, (2) smooth finishing of tooth surfaces, and (3) high accurate hobbing.

Finish Hobbing with High Speed Steel (HSS) Hobs

High speed steel finishing hobs with many gashes and positive rake angles can reduce the size of built-up edges because of the thinner undeformed chip thickness and the positive rake angle. They make the tooth surface smooth, resulting in a few micrometers in peak-to-valley height (*Ry*). A cutting speed of about 20 meters per minute is used for medium hardness gears (300–400HBW) to make BUE small and flank wear rate slow.

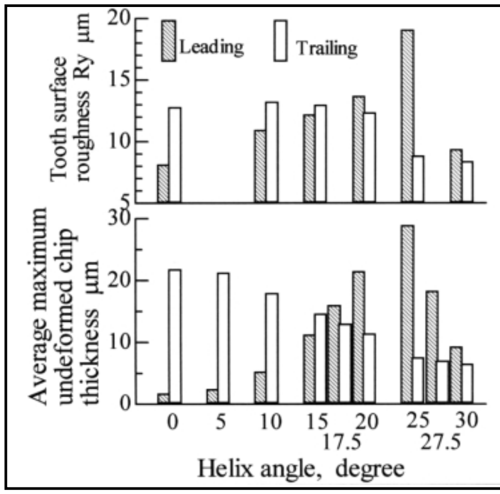
For this paper, we use AISI M35 high speed steel for our comparisons. Figure 1 shows the calculated result of undeformed chip thickness in hobbing. The vertical axis indicates divided layer numbers in vertical sections of the tooth trace. The horizontal axis indicates divided points of the hob tooth profile. The undeformed chip thickness is displayed in micrometers. When each hob tooth passes through many line segments planted in the tooth space, the length of each line segment cut is calculated and converted to an undeformed chip thickness (Ref. 9). The relationship between the maximum thickness removed by the cutting edge at the involute generating portion (Point Q) and the BUE formation is investigated.

Figure 2 shows the relationship between the maximum thickness and the tooth surface roughness in conventional hobbing of right-handed helical gears with various helix angles. The maximum thickness is an average value of the thickness removed by every cutting edge at the generating portion. It is clearly found that the difference in roughness at both flanks and for each helix angle results from the difference in the corresponding maximum thickness respectively. Specifications of the hob, such as outside diameter, number of threads, number of gashes and rake angle, etc., have great effects on the chip thickness and/or the formation of BUE.

Figure 3 shows the effect of the number of gashes on the maximum thickness at the generating portion. Experiments are carried out using two hobs with 12 and 18 straight gashes. The tooth surface roughness is shown in Figure 4. It can be seen that, for both spur and helical gear hobbing, the corresponding maximum thickness becomes smaller by increasing of the number of gashes. This results in relatively better surface finishes.

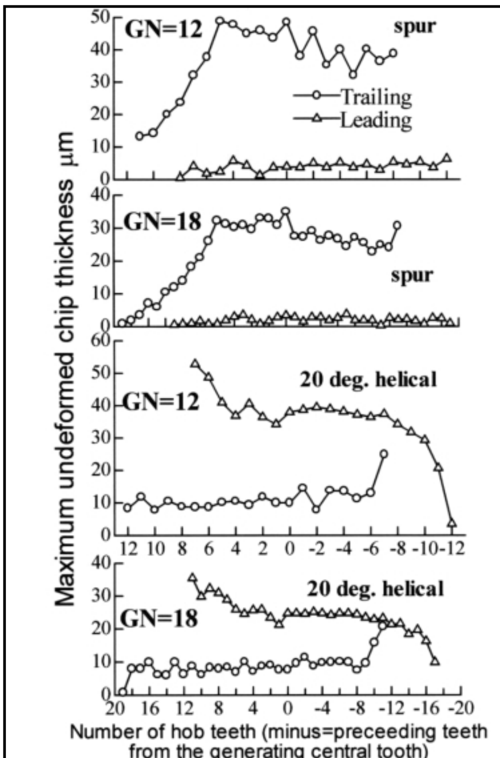
In order to investigate the relationship between the rake angle and the formation of BUE, the size of BUE is measured. Figure 5 shows the size of BUE projecting out on the rake face, which is measured at the involute generating portion of each hob tooth. These two hobs have an equal number of gashes. The maximum thickness removed by them will be about the same in both cases. Large differences in the size of BUE exist; that is, the BUE in the case of the 15° rake angle hob is smaller than that with the 0° rake angle hob. Particularily on the trailing side cutting edge, where usually large chip thicknesses would be removed during spur gear hobbing, a decrease of BUE can be seen in the case of 15° rake angle hobbing. Figure 6 shows the tooth surface roughness. This figure points out that the rake angle has a great influence on cutting with the cutting edge, which removes large chip thickness.

Recently, improving the environment and conserving resources have been needed as well as higher productivity of gear finishing. The changes have led to finish hobbing using cermet and cemented carbide hobs without cutting fluids. Coated HSS hobs are also used to finish at high speeds. However, when the rake face of the hob is not covered with the coating film after regrinding, the finished tooth surface sometimes deteriorates.



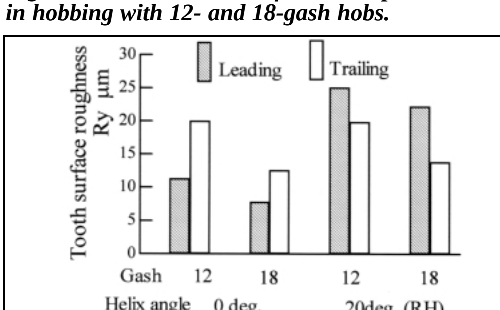
Normalized 0.35% carbon Cr-Mo steel 210HBW, module 3, equivalent no. of teeth 42, RH Helical gear/M35 (no coated HSS), ϕ80, 1-thread (RH), 12 gashes/20 m/min, feed 1.5 mm/rev., wet, conventional hobbing.

Figure 2—Relationship between the maximum thickness and the tooth surface roughness.



(Module 6, RH helical gear, 1-thread (RH) hob, conventional, equal to Fig. 4)

Figure 3—Maximum undeformed chip thickness in hobbing with 12- and 18-gash hobs.



Quenched & tempered 0.40% carbon Cr-Mo steel 320HBW, module 6, z31(Spur), 26(20 deg. RH Helical) / M35(no-coated), 1-thread(RH), ϕ115 / 20 m/min, feed 1.5 mm/rev., wet, conventional hobbing, finishing stock of one side flank 0.1–0.2 mm).

Figure 4—Tooth surface roughness in hobbing with 12- and 18-gash hobs.

Dr. Yasutune Ariura
has been a professor in the Kyushu University Department of Intelligent Machinery and Systems of of Fukuoka, Japan, since 1983. His field of study is gear manufacturing with an emphasis on finish hobbing with cermet- and CBN-tipped hobs, load carrying capacity of hardened, tempered, and surface hardened cylindrical gears as well as the manufacturing and performance of austempered ductile iron gears.

Dr. Yoji Umezaki
has been a research assistant in Kyushu University's Department of Intelligent Machinery and Systems since 1973. His areas of expertise are the analysis of gear hobbing mechanisms, the decrease of hob wear, the improvement of tooth surface roughness of hobbed gears, the analysis of the tooth profiles of hobbed gears, accurate hobbing, and finish hobbing of surface hardened gears with CBN hobs.

Table 1—Chemical compositions and mechanical properties of cermet and carbide tips.

	Chemical Compositions wt%			Mechanical Properties		
	WC	(Ti, Ta, Nb, Mo)CN	Ni, Co	HV	Specific gravity	TRS*
Cermet HTP20	16	68	16	1550	7.0	1960
Carbide HWM10	80.5	14	5.5	1730	12.9	1670

TRS*: Transverse Rupture Strength (N/mm²)

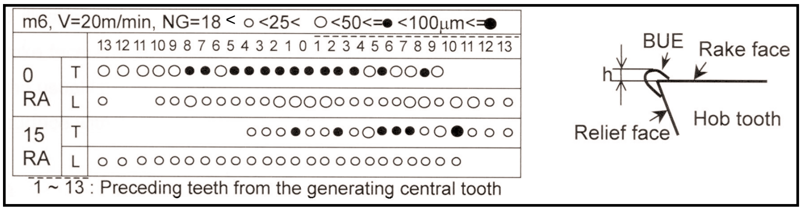


Figure 5—Size of BUE (h) projecting out on the rake face.

(Quenched & tempered 0.40% carbon Cr-Mo steel 320HBW, module 6, no. of teeth 31(Spur), 26(20 deg. RH Helical) / 1-thread(RH), 18-gashes, 115-diameter, M35 (no-coated HSS) / 20 m/min, feed 1.5 mm/rev., wet, conventional hobbing, finishing stock of one side flank 0.1–0.2mm)

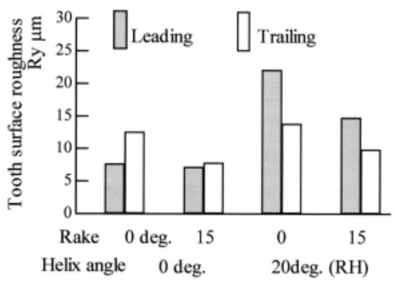
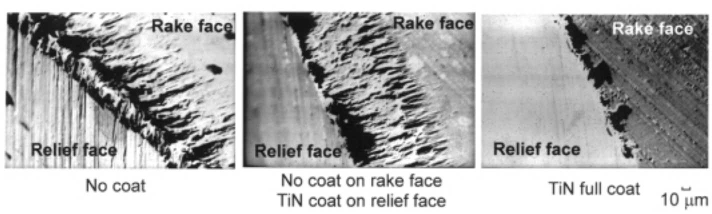


Figure 6—Tooth surface roughness in hobbing with 0° and 15° rake angle hobs.



(Normalized 0.35% carbon Cr-Mo steel 210HBW, module 3, no. of teeth 42 Spur / M35 (no-coated), 80-diameter, 1-thread (RH), 12-gashes / 20 m/min, feed 1.5mm/rev., wet, conventional hobbing).

Figure 7—Back scanning electron photographs of the coated and uncoated tool edges.

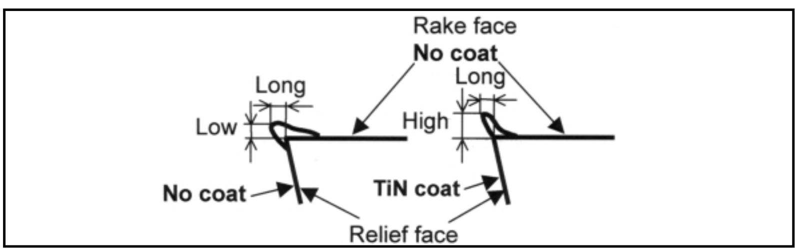
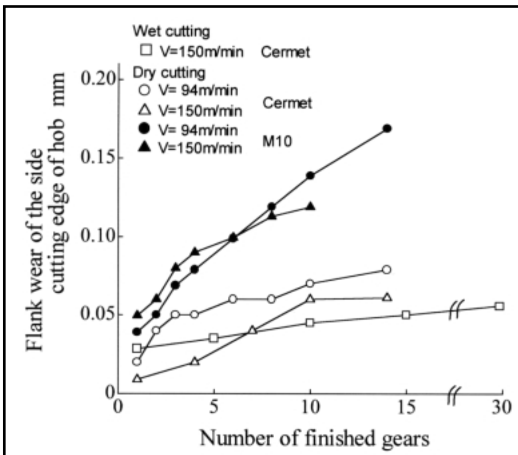


Figure 8—Illustration of the BUE on tool edge.



(Quenched & tempered 0.40% carbon Cr-Mo steel 320HBW, module 6, no. of teeth 31, Face width 55 mm / 1- thread(RH), 150-diameter, 18-gashes, Rake angle = Cemented carbide (M10) 10°, Cermet 0° / feed 1.5 mm/rev., conventional hobbing, finishing stock of one side flank 0.1–0.2 mm)

Figure 9—Wear width of cermet and cemented carbide tipped hobs.

The main cause of the degraded tooth surface is the occurrence of the built-up edge produced on the rake face and the attached fragments as shown in Figure 7. Figure 8 illustrates the adhesive fragments on the rake face. In the case of a hob with an uncoated rake face and a coated relief face, the adhesive fragments are piled higher than in the case of the usual HSS hobs. Few adhesive fragments exist as they do on coated surfaces, such as TiN, TiC, TiAlN and so on.

Finish Hobbing With Cermet-Tipped Finish Hobs

For finishing low and medium hardness gears (160–400HBW), cermet-tipped finish hobs show superior performance to cemented carbide hobs in the wear resistance and the tooth surface qualities. (See Table 1 for chemical compositions and mechanical properties of cermet and carbide tips discussed in this paper.) The cermet-tipped hobs can be applied to higher cutting speeds than the cemented carbide hobs, as the chipping resistance of cermet was recently improved via high transverse rupture strength. The cutting speed of the cermet hob is about 100–200 meters per minute, even in module 6–8 for medium hardness gears. The wear mechanism in cermet and cemented carbide hobs is mainly abrasive, and flank wear is more dominant than crater wear. The accuracy of tooth profile and normal pitch of the cermet hob has a great influence on the tooth profile of finished gears. The finished tooth profile is excellent in the case of hobbing, with the cermet hobs having cutting edges with land width less than about 0.1 mm. Cermets have low affinity with the steel, so they hardly make adhesive fragments on the cutting edges, and they do not require coatings such as TiN. The cermet hob can finish steel gear teeth very smoothly and accurately.

Figure 9 shows the changes in flank wear in finish hobbing with the cermet- and the cemented carbide-tipped hobs. The amount of wear is measured at the leading-side cutting edge and is an average value of the five most-worn teeth. The wear of the cermet finishing hob is about one-third that of the cemented carbide finishing hob when 14 gears are cut. As no chipping of the cermet finishing hob is found under any of these cutting conditions, the stability of the cermet hob for intermittent cutting is excellent. Cutting oil hardly affects the tool wear under these cutting conditions.

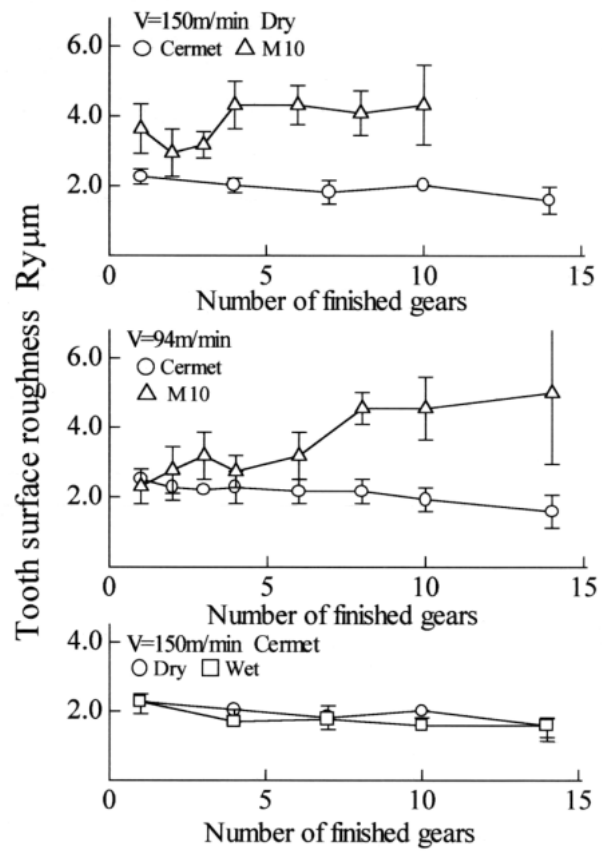
Figure 10 shows the change in tooth surface roughness with the cermet finishing hob and the cemented carbide hob in the case of cutting speeds under dry and wet conditions. The tooth surface roughness obtained by the cermet finishing hob is about half compared with that obtained by the cemented carbide hob; moreover, the variation of tooth surface roughness is very small. The difference of tooth surface roughness in dry cutting and wet cutting is hardly observed.

The roughness of the relief and rake surfaces of the cermet finishing hob are shown in Figure 11. The roughness (*Ry*, peak-to-valley height) is about 0.15 micrometers on the rake surface and about 2.0 micrometers on the relief surface. The roughness of the relief surface is much larger than that of the rake surface. As the shape of the cutting edge is influenced by the irregularity of the relief surface, the tooth surface roughness becomes the same roughness as the relief surface of the hob by transfer. The improvement of the tooth surface roughness is expected by making the relief surface of the hob smooth.

Figure 12 shows the tooth profile curves of gears finished with the cermet finishing hob. The tooth profile is very accurate (ISO class 5) and is minimally degraded because the hob wear occurs at a low rate.

Figure 13 shows photographs of tooth surfaces hobbed with cemented carbide- and cermet-tipped finish hobs. In the case of cemented carbide finish hobbing, many scratches are seen on the tooth surface, as shown in Figure 13(a). This is due to the occurrence of the phenomenon of “chip adhesion” and the formation of BUE (Ref. 4). The surfaces finished with cermet-tipped hobs are very smooth and have no scratches in dry and wet cuttings, as shown in Figure 13(b).

The land at the side cutting edge is useful for improving the hob tooth profile. Figure 14 shows the relationship between the land width and hob flank wear. This data is obtained from one side flank finishing test. In the case of land width of about 0.1 mm, the wear rate at the leading-side edge is slightly different from the case without land. When the flank wear width including the land becomes greater than about 0.25 mm, chipping and flaking occur at the land, resulting in a greater vibration of the hobbing machine and a degradation of surface finish. By attaching the land, the tooth profile error in involute helicoids of hob teeth decreases from 10 micrometers to 5 micrometers, and the pitch error decreases from 8 micrometers to 4 micrometers. The tooth surface roughness is shown in Figure 15. The roughness of the sharp edge (roughness of relief surface) without land is about 2.5 micrometers, and the finished surfaces have about the same roughness regardless



(Condition; equal to Fig. 9)

Figure 10—Tooth surface roughness in finish hobbing.

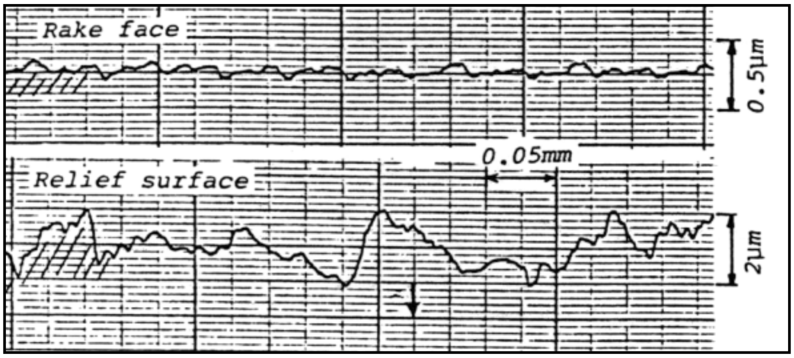


Figure 11—The relief and rake face roughness of the cermet finishing hob.

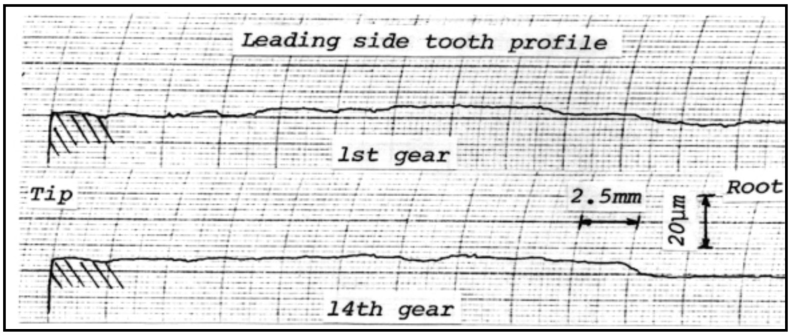


Figure 12—The tooth profile curves of finished gears with the cermet finishing hob.

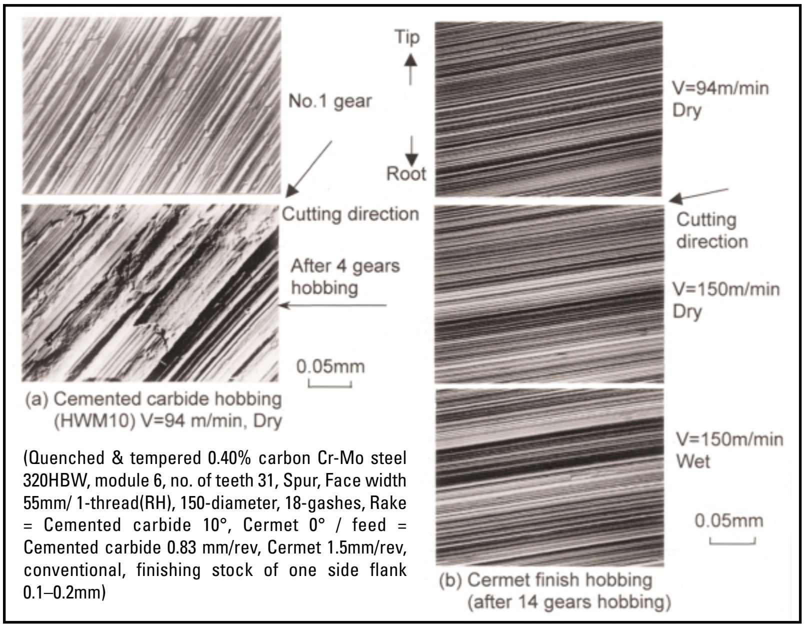


Figure 13—Back scanning electron photographs of tooth surfaces.

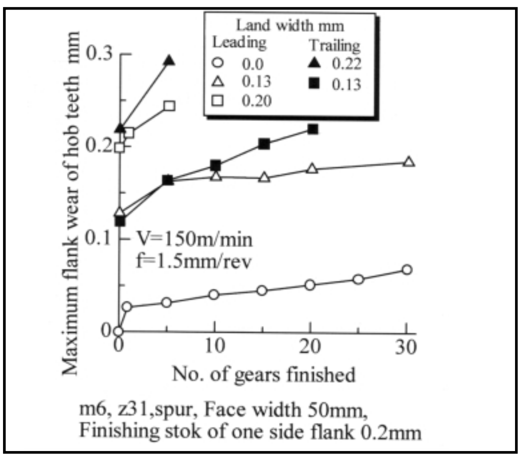


Figure 14—Flank wear of the cermet tipped hob with land width.

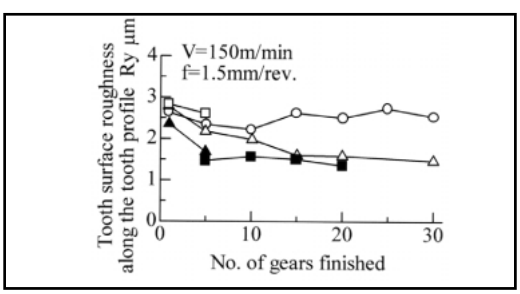


Figure 15—Tooth surface roughness finished with cermet tipped hobs with land.

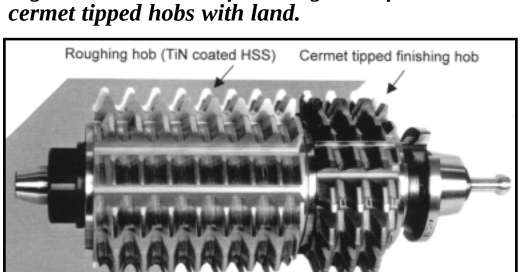


Figure 16—The combination of the roughing hob and the finishing hob.

of number of finished gears. However, the surface roughness becomes smoother after the wear width, which does not include the land width, is greater than 40–50 micrometers in the finishing with land. It is considered that burnishing occurs between the tooth surface and the wear land.

The cermet finish hob is often used for finishing annealed or normalized low carbon alloy steel, though this hob has been developed for quenched and tempered alloy steel. Figure 16 shows the combination of the roughing hob made with TiN-coated high speed steel and the cermet-tipped finishing hob. The cermet hob has a short hob length because of its low wear rate. Using this method, it is possible to omit the shaving process.

Finish Hobbing of High Hardness Gears with CBN-Tipped Hob

Skiving hobs tipped with cemented carbide are used for high hardness, case hardened gears. Skiving hobs are difficult to keep their tooth profile accurate after regrinding owing to the large negative rake angle. The authors have newly developed a CBN-tipped hob, which has many gashes and a 0° rake angle. The CBN tip has low CBN concentration of about 50% boron nitride with ceramic binders (e.g., TiN). Chipping and/or flaking are observed as a dominant wear mode. The CBN-tipped hob shows an excellent cutting performance at a high speed of 600–900 meters per minute for finishing case hardened gears. This is used sufficiently to the extent of the flank wear of 0.15 mm except chamfering width and small chipping. An important technique in manufacturing the CBN-tipped hob is to grind the cutting edges smoothly without chipping. Although CBN tips and their resharpening cost are expensive, the CBN-tipped hob has a possibility for efficiently finishing case hardened gears.

A finishing hob was manufactured for trial using a CBN tip with best wear resistance in fly-tool tests. Hobbing conditions are shown in Table 2. Test gear blanks of chrome molybdenum steel (JIS SCM415) are case hardened to 60HRC at the tooth surface and about 550HV0.1 at 1.2 mm from the surface. The cutting edges of the hob teeth are chamfered by honing with 30–50 micrometers in size on the relief surface. The shape of the CBN-tipped hob is shown in Figure 17.

Figure 18 shows a hobbing test with a CBN-tipped hob on a CNC hobbing machine at 900 meters per minute. The test cutting can be carried out smoothly in spite of spark showers. Chips are blown away by compressed air from the upper part of the hob. Many melted chips are seen, and most of them become spheres, as shown in Figure 19. The removal of hot chips is an important problem because they can cause thermal distortion of the machines and damage the surroundings.

Figure 20 shows the wear curves of hob teeth numbers –15 through –19 which precede the central generating tooth and cut chips with relatively larger volumes than the other teeth. The sizes of wear land do not include the size of the chamfer land. In speeds less than 300 meters per minute, the wear of each tooth is small and its wear rate is low. The flank wear of the group of 600–900 meters per minute is about three times to four times as large as those of 150 and 300 meters per minute. The wear rate at 600 meters per minute is low, and the new chipping does not occur during hobbing, except the chipping by grinding when sharpening.

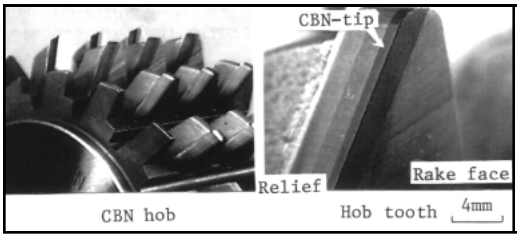
Photographs of these cutting edges are shown in Figure 21. The chipping is apt to occur during grinding of the hob teeth, and it remains after chamfering as shown in Figure 21(a) and (b). New chipping hardly occurs by hobbing; that is, the number and size of chippings are maintained as grinding sharpens the hob. The flaking on the cutting edge occurs just after 10 gears are hobbed at 900 meters per minute. It is seen that this flaking may occur from the –19 tooth to the –16 tooth continuously.

Figure 22 shows the flaking on the No. –19 tooth and its depth. The depth at the deepest point is about 23 micrometers, and it flakes along the edge in the range of about 0.75 mm. Thermal cracks are not found. The adhesive fragments are found on the edge after hobbing in the high-speed tests of 900 meters per minute. It will become an important matter that the behavior of the adhesive fragments is clarified and the method of eliminating the adhesive fragments is investigated.

Figure 23 shows the size of chipping on the relief surface including the chamfer size in tooth numbers –15, –17, –18 and –19. Micro-chippings occur on many hob teeth. The maximum size of chippings is about 0.1 mm. The chippings do not change in size and in number with respect to the number of gears hobbed.

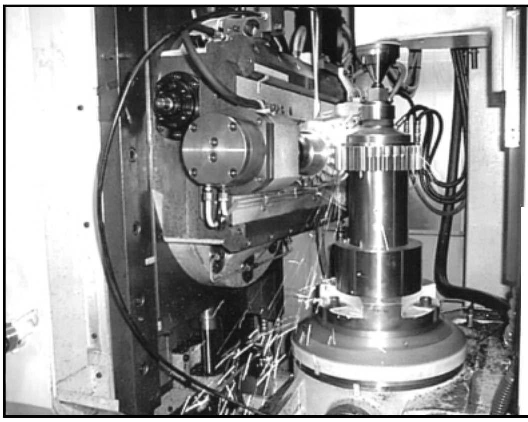
Figure 24 shows the tooth surface roughness of hobbed gears. The roughness at the cutting speed of 300 meters per minute is about 1.0 micrometers in *Ry*, and this value is superior when compared with roughness of other conditions. The roughness remains almost constant, even as the number of gears hobbed increases,

Table 2—Test conditions.	
Cutting speed	150, 300, 600, 900 m/min.
Feed	1.5 mm/rev.
Finishing stock	0.1 mm/one side flank
Hobbing machine	NC machine
Hobbing method	Conventional, Dry cutting



(m6, 1-thread (RH), 150-diameter, 18-gashes, 0 deg. Rake angle)

Figure 17—CBN-tipped finishing hob.



(V=900 m/min, f=1.5 mm/rev., Dry, Conventional / m6, Spur, no. of teeth 31, 60HRC, Case-hardened SCM415(JIS) / 1- thread(RH), 150-diameter)

Figure 18—CBN finish hobbing test.

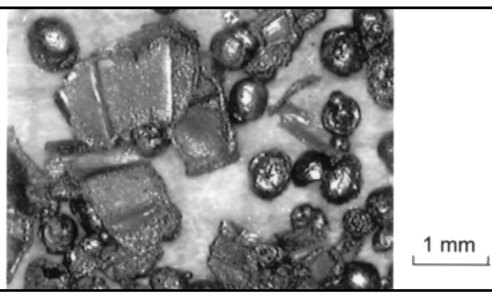
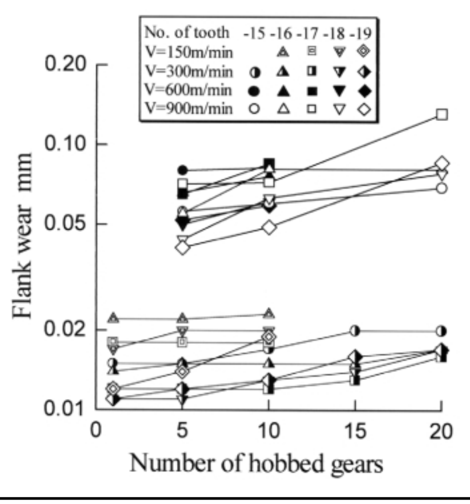


Figure 19—Chips at 900 meters per minute.



(Gear; Case-hardened 0.15% carbon Cr-Mo steel (SCM415) 60HRC, module 6, no. of teeth 31, Face width 55 mm / Hob; 150-diameter, 1-thread(RH), 18-gashes, 0° Rake / Condition; 900 m/min, 1.5 mm/rev., Dry, Conventional hobbing, finishing stock of one side flank 0.1 mm)

Figure 20—Flank wear of CBN-tipped finishing hob.

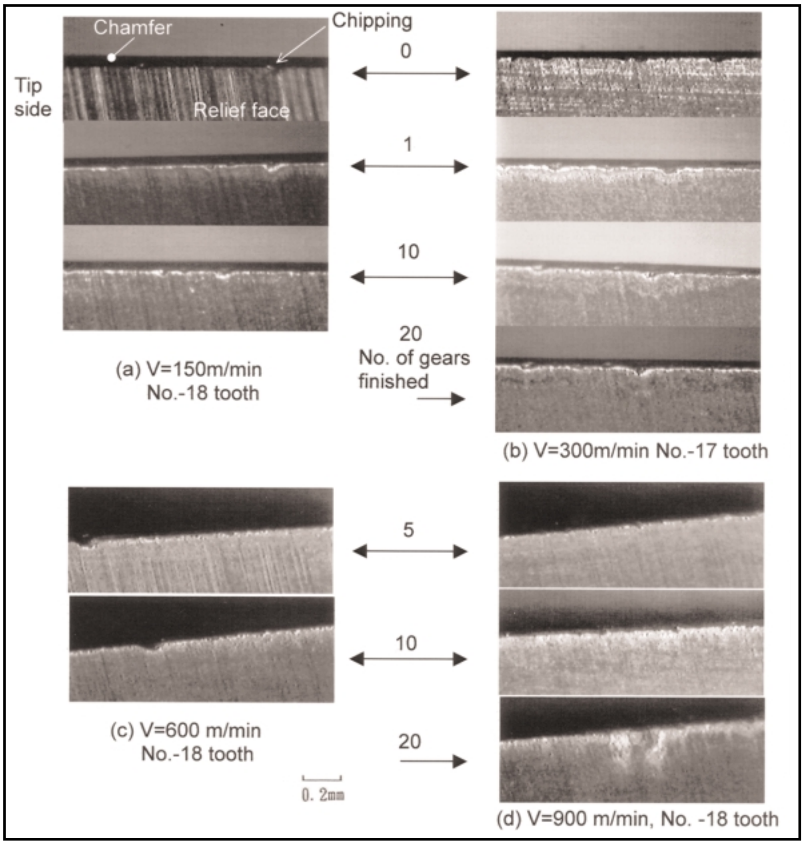


Figure 21—Photographs of flank wear and chipping.

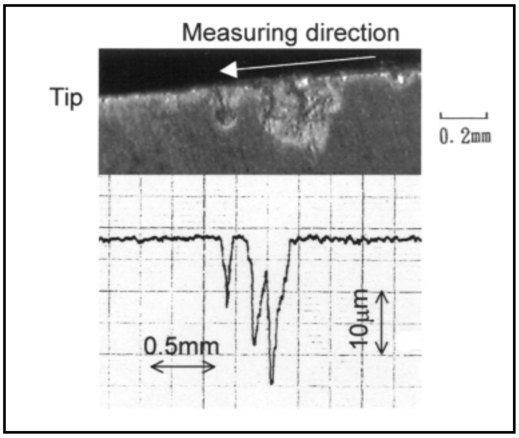


Figure 22—Flaking wear and depth.

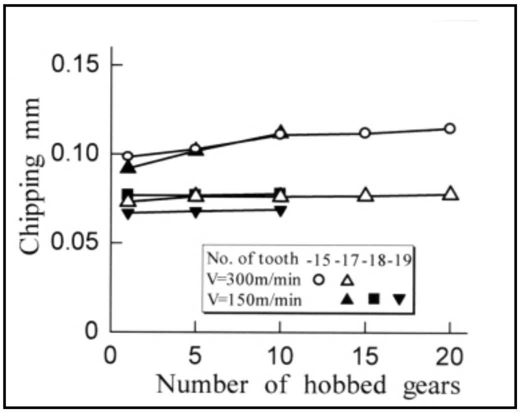


Figure 23—Chipping of CBN-tipped hob at 300 and 150 meters per minute.

and its scatter is narrow. The roughness *Ry* is 1.8–2.4 micrometers on the relief surface of the CBN-tipped hob and 0.2–0.5 micrometers on its rake surface. To finish the relief surface of CBN-tipped hobs smoothly contributes to the improvement of roughness of tooth surfaces hobbed.

Figure 25 shows the tooth profile and the tooth trace of gears hobbed (after 10 gears cut) at the cutting speed of 150 meters per minute. No scratch is found on these profiles. The tooth profile is ISO class 5, that is, about 8 micrometers. The tooth profile and the tooth trace of the trial CBN-tipped hob are about 8 and 6–8 micrometers, respectively.

Figure 26 shows the tooth profiles measured and calculated (Ref. 10) at 900 meters per minute. The tooth profile error is caused by the hob accuracy and the hob eccentricity in setting. Improving the accuracy of the CBN-tipped hob and minimizing the hob eccentricity in setting can achieve excellent accuracy of hobbed gears. The method of tooth grinding of a CBN-tipped hob is a very important factor from a point of view of the hobbed gear accuracy and surface roughness.

Conclusion

For medium hardness gears, the cermet finishing hob is superior in wear resistance and improvement of tooth surface roughness to the cemented carbide finishing hob. The cermet-tipped finish hob is now often used for not only medium module gears such as construction gears, but also small module gears such as small vehicle gears before heat treatment of case hardened steels. The following results and knowledge are obtained.

1. Higher speed cutting (near 150 meters per minute) makes the hob life longer and makes it easy to remove chips from the cutting edge.

2. The cutting edges of the hob teeth should be finished as smoothly as possible, as the irregularity of the cutting edge affects the tooth surface roughness.

3. Chips should be removed completely from the cutting edge after each cutting to improve the tooth surface roughness.

For surface hardened gear materials, CBN tips that have a low CBN concentration (about 50% wt) with ceramic binders are superior in wear and chipping resistance. The CBN-tipped hob made for the trial has excellent wear resistance. The chipping of cutting edges is apt to occur during sharpening of hob teeth, and it influences the surface roughness, though it does not progress during hobbing. Therefore, the prevention of chipping and the improvement of surface roughness in grinding of CBN-tipped hobs are considered to be very important.

The hobbing test at 900 meters per minute of case hardened steels suggests the importance of clarifying the behavior of adhesive fragments for the suppression of flaking and chipping.

Acknowledgments

The authors thank Sumitomo Electric Industries, Ltd. and Azumi Mfg. Co., Ltd. for their support of cermet and CBN tips and manufacturing for trial of cermet- and CBN-tipped hobs, respectively. (This paper was previously published by Gesselschaft Entwicklung Konstruktion Vertrieb at the International Conference on Gears, Vol. 1., VDI-Berichte 1665, Düsseldorf, VDI Verlag 2002, pp. 129–143. Printed with the friendly permission of VDI Verlag GmbH.)

References

1. Ariura, Y., T. Nakanishi, T. Ueno and H. Nara. “Manufacture and Performance of Cylindrical Gears (An Application of New Finish-Hobs for Increasing Surface Durability),” *JSME International Journal*, Vol. 30, No. 267, 1987, pp. 1480–1486.
2. Ishibashi, A., S. Tanaka, and S. Ezoe. “Changes in Contact Surfaces and Surface Durability of Highly Loaded Gears with Roughnesses of 0.1 to 15 µm Rmax,” *Proceedings of the 12th Leeds-Lyon Symposium on Tribology*, 1985, pp. 339–346.
3. Ariura, Y., Y. Umezaki and H. Nara. “Finish Hobbing of Medium Hardness Gears with Cermet-Tipped Hobs,” *Proceedings of the 1989 ASME International Power Transmission and Gearing Conference*, 1989, pp. 691–696.
4. Yonekura, M. and M. Ainoura. “A Research on Finishing Hardened Gears of Large Modules,” ASME, 80-C2/DET-62, 1980.
5. König, W., L. Meijboom, and H.D. Schäfer. “Teilwälzscheiben von einsatzgehärteten Zylinderräden mit CBN Doppel kegelscheiben,” *Antriebstechnik*, 20-7/8. 1981, pp. 314–317.
6. Tsukamoto, R. and F. Haga. “CBN Gear Grinding Technologies for Automotive Gears,” *Proceedings of JSME International Conference on Motion and Power Transmission*, 1991, pp.197–202.
7. Faulstich, I. “CBN-Profile Grinding Cylindrical Gears Using Galvanically Bonded Wheels,” *Proceedings of JSME International Conference on Motion and Power Transmission*, 1991, pp. 213–218.
8. Ariura, Y., Chiu Hua and Y. Umezaki. “Improvement of Gear Accuracy in Gear Hobbing (1st Report, A Numerical Analysis of Tooth Profile Errors),” *JSME International Journal*, Vol. 30, No. 259, 1987, pp. 168–174.

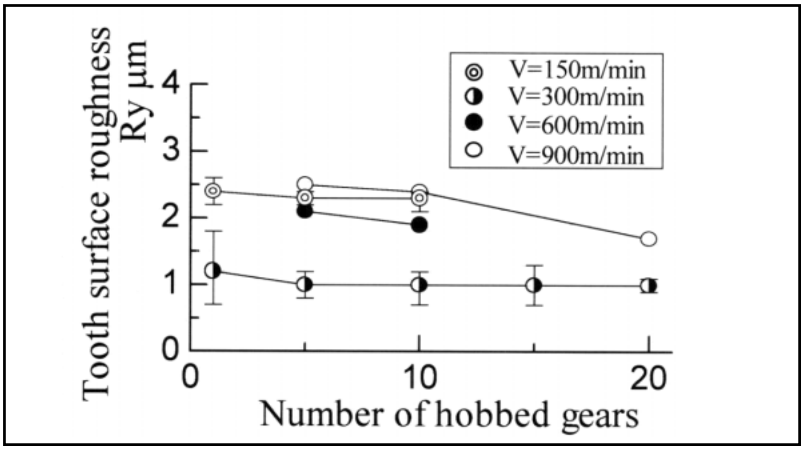


Figure 24—Tooth surface roughness after CBN-tipped hob finishing.

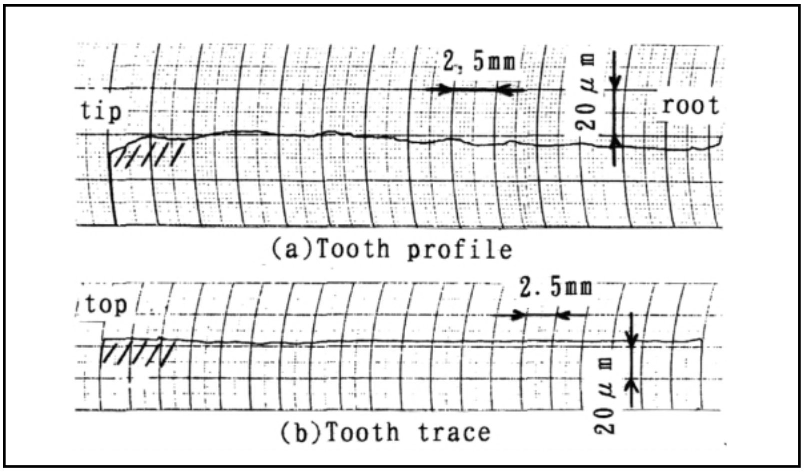


Figure 25—Tooth profile and tooth trace after 10 gears finished with CBN-tipped hob (150 meters per minute).

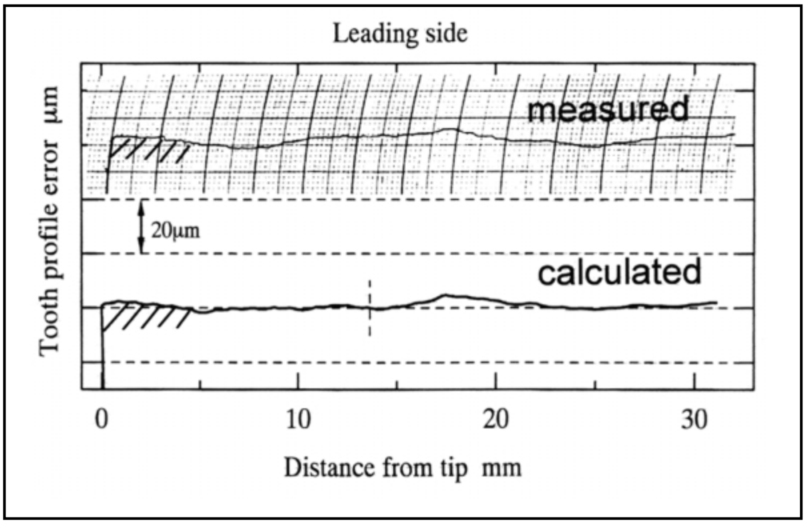


Figure 26—Tooth profile and tooth trace after 20 gears finished with CBN-tipped hob (900 meters per minute).