High Speed Hobbing of Gears With Shifted Profiles

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Abstract:

Most reduction gears currently manufactured for automobiles and other vehicles are profile-shifted gears.[1]

Therefore, the authors have examined the damage on hobs for profile-shifted gears (spur and helical) with larger outside diameter (long addendum) or smaller outside diameter (short addendum) to improve the design and lengthen the life of a hob.

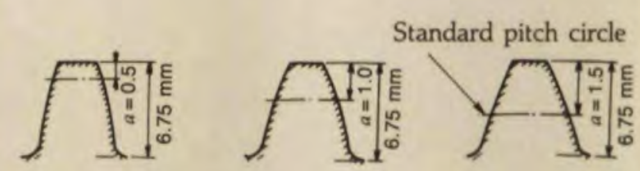
Introduction

The newer profile-shifted (long and short addendum) gears are often used as small size reduction gears for automobiles or motorcycles. The authors have investigated the damage to each cutting edge when small size mass-produced gears with shifted profiles are used at high speeds.

Table 1 shows the dimensions of hobs and profile-shifted gears in an experiment. The hob has a module m=3 and an outside diameter of 110mm. It is made of high speed M34 steel, triple-threaded, built-up and TiN-coated.[2] In this experiment, three kinds of profile-shifted gears were prepared: (A) a short addendum gear with a coefficient of addendum modification of $a=0.5$ and a smaller outside diameter of $2(1-a)$m; (B) a standard gear ($a=1.0$) without shift; (C) a long addendum gear where ($a=1.5$) and with a larger outside diameter of $2(a-1)$m. The whole depth of cut is 6.75mm. Fig. 1 shows the hobbing method. Each cutting blade is numbered to show the wear of each cutting edge.

Table 1 Dimensions of hobs & profile shifted gears

Dimensions of tested hobs:				
Normal module	m	3	3	
Normal pressure angle	PA	20°	20°	
Number of threads		3.RH	3.RH	
Outside diameter	D	110mm	80mm	
Lead angle	LA	5°04′	7°06′	
Rake angle		0°	0°	
Number of flutes	N	12	10	
Material & Coating		M34+TiN	M34+TiN	
Normal tooth profile		Standard	Standard	
Dimensions of profile shifted gears:				
Normal module	m	3	3	3
Normal pressure angle	PA	20°	20°	20°
Helix angle	HA	0°	15°	30°
Number of teeth	Z	47	47	57
Coefficient addendum	a	0.5~1.5	0.5~1.5	0.5~1.5
Cutting length/1 gear	l	2.5m	2.8m	2.0m
Material	AISI	1045	1045	4118
Hardness	BHN	180	180	140
Hobbing machine: KS-14, Cutting oil: HS-4M				



(A) Short addendum gear (B) Standard gear (C) Long addendum gear

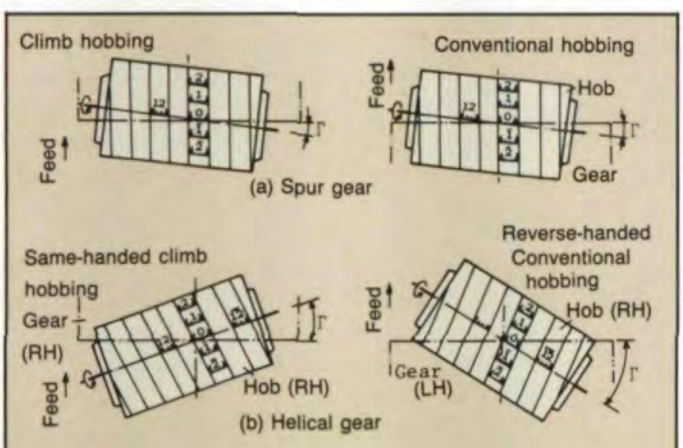


Fig. 1—Hobbing method.

Hobbing of Spur Gears

Generally, a spur gear of carbon steel S45C (AISI 1045), which is often used for motorcycle reduction gears and geared motors, is used at a cutting speed of 40–80m/min. in climb-cut.

Fig. 2 shows the maximum relief wear of each cutting edge after 13 spur gears of carbon steel with various addendum modifications (cutting length: l = 32.4m) were hobbed at a

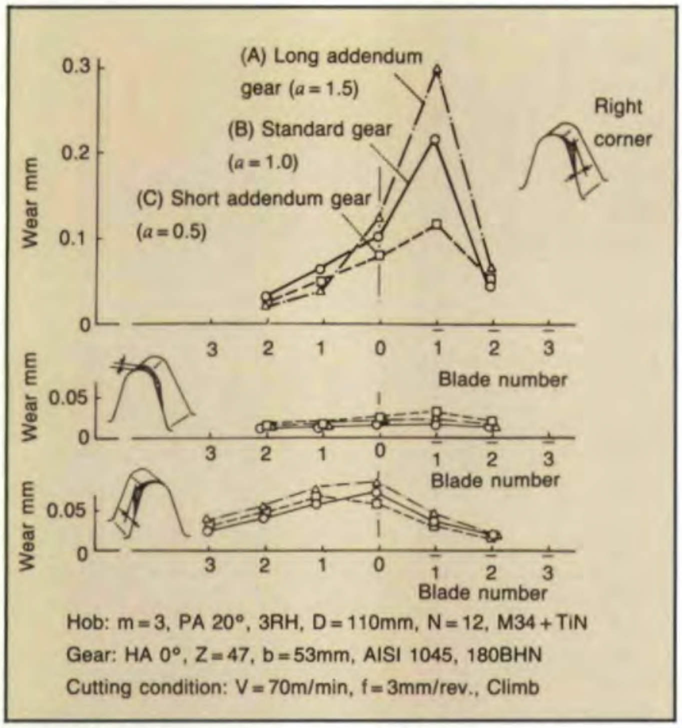


Fig. 2 – The relief wear on each cutting edge of spur gear with various addendum modifications (l=32.4m).

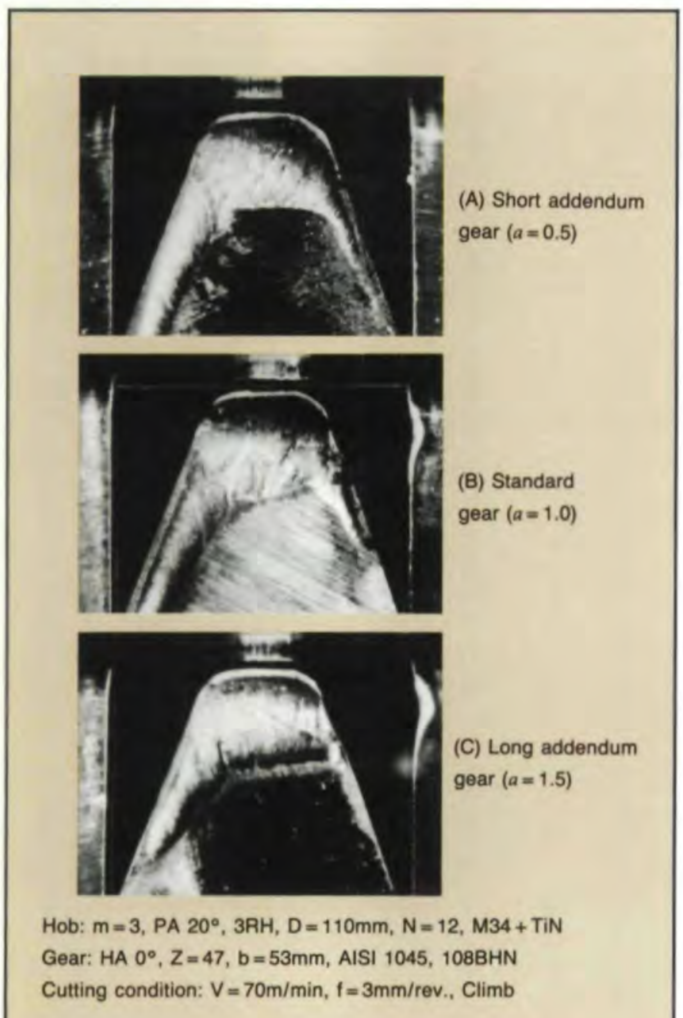


Fig. 3 – Damage to the blade No. $\bar{1}$ where the maximum relief wear occurred (l=32.4m).

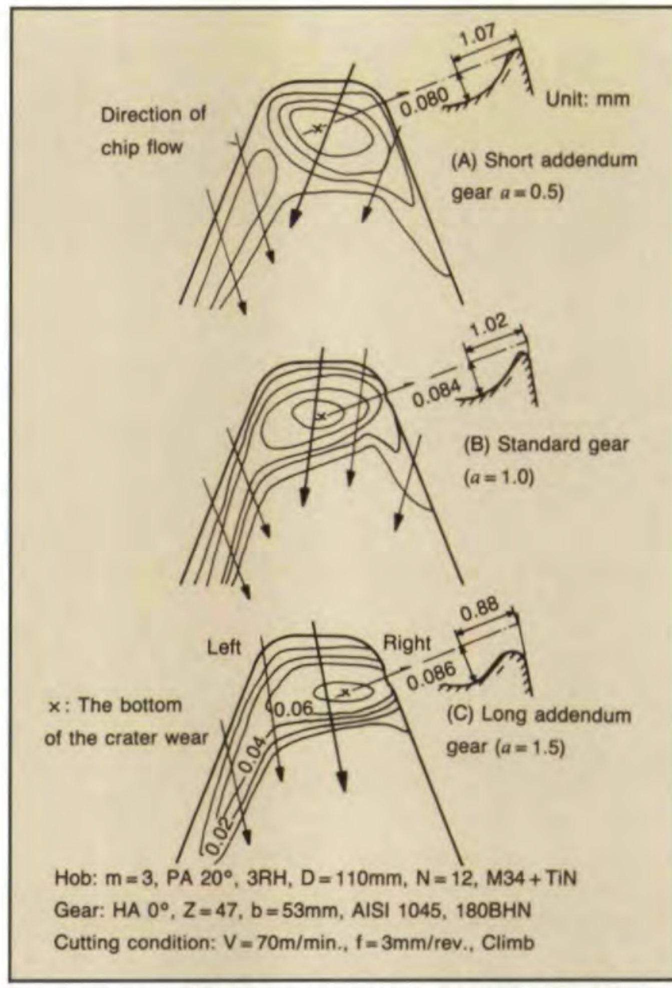


Fig. 4 – Direction of chip flow on each crater (Blade No. $\bar{1}$, l=32.4m).

cutting speed of 70m/min. and a feed of 3mm/rev. There is little difference in wear at the top cutting edge and the left corner, but the cutting edge No. 1 at the right corner, where the maximum relief wear occurred, is greatly influenced by the addendum modification. The amount of corner wear for long addendum gears is the largest. The standard gear (B) has less wear than (C), and short addendum gear (A) has the least wear. Fig. 3 shows the damage to the blade No. 1 where the maximum relief wear occurred. In the case of hobbing short addendum gears, crater wear occurs on each cutting edge at the top, right corner and left corner, but nothing is yet broken down. In the standard and long addendum gears, the cutting edge at the right corner is broken down because of crater wear, causing extraordinary amounts of relief wear.

Fig. 4 shows the depth of crater wear with contour lines every 0.02mm and the direction of chip flow on each crater as observed using a microscope. In (A), a short addendum gear, cutting chips that come out from the top cutting edge and the right corner flow to the left cutting edge, but the chip flow from the left corner keeps them away from the left corner. Both cutting edges at the right and left corner are hardly broken down because crater wear is distant from each cutting edge, decreasing corner wear.

On the other hand, in the case of (C), a long addendum gear, cutting chips flow to the right cutting edge without obstruction because the right edge does not cut. Accordingly,

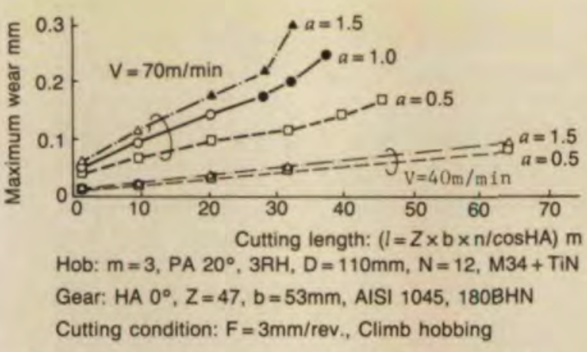


Fig. 5 – Progress of the maximum relief wear in case of climb hobbing (HA 0°).

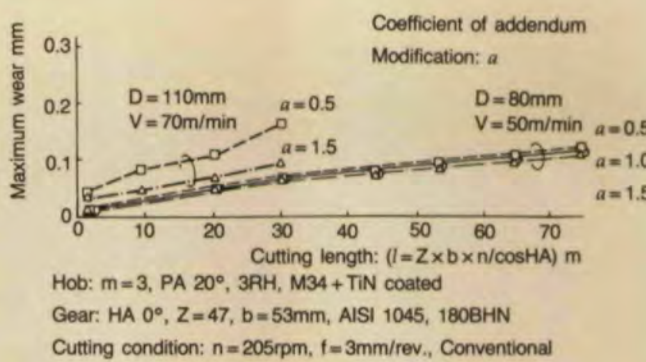


Fig. 7 – Progress of the maximum relief wear in case of conventional hobbing (HA 0°).

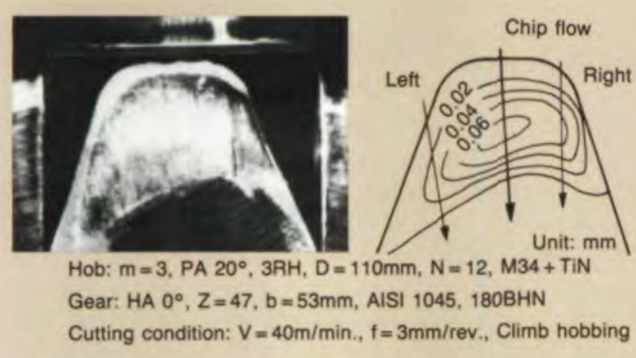


Fig. 6 – Influence of cutting speed (Long addendum gear, a=1.5, Blade No. $\bar{1}$, l=65m).

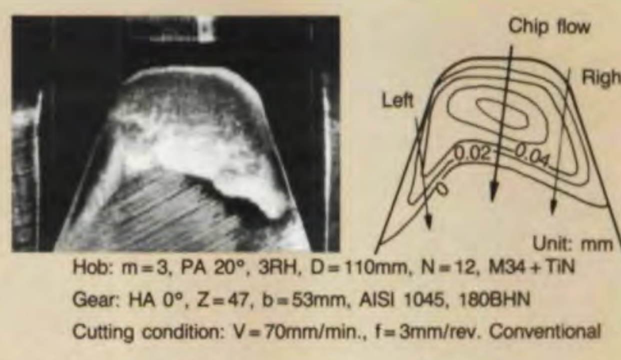


Fig. 8 – Influence of hobbing method (Long addendum gear, a=1.5, Blade No. $\bar{2}$, l=32.4m).

the crater wear along the chip flow grows and extends to the right corner cutting edge. Then the cutting edge is broken down as the corner wear increases, and the bottom of crater wear moves along the chip flow as the number of gears cut increases.[3] In case (C), the bottom of crater wear comes close to the cutting edge at the right corner; that is, the area of highest temperature is much closer to the cutting edge at the right corner, therefore, the cutting edge is broken down more easily.[4]

Fig. 5 shows the amount of maximum relief wear when gears with various addendum modifications are cut. Each solid symbol indicates the relief wear caused by the growth and breakdown of the crater wear. In the case of high speed climb hobbing of spur gears, the life of the hob is shortened when long addendum gears with larger outside diameters are cut. It can be lengthened for short addendum gears with smaller outside diameters. The thin line describes the progress of the maximum relief wear when the cutting speed is 40m/min. Addendum modification has little influence on the relief wear when the cutting speed is slow. Fig. 6 shows the damage on a blade No. $\bar{1}$ with the maximum relief wear when a long addendum gear (C) is climb hobbed at a cutting speed of 40m/min. The crater wear grows slowly when the cutting speed is reduced. The cutting edge at the right corner is not broken down, even with the 65m cutting length of long addendum gears. But the cutting edge at the right corner is nearly broken down, and the relief wear will increase soon after the cutting length increases.

Fig. 7 shows the progress of the maximum relief wear in the case of conventional hobbing at a speed of 70m/min. Other cutting conditions remain the same. In this figure, addendum modification is less influenced than in the results of climb hobbing shown in Fig. 5. The thin line describes the maximum relief wear in case of a hob 80mm outside diameter.[5-6] Fig. 8 shows the damage to a blade No. $\bar{2}$ with the maximum relief wear when long addendum gears are conventionally hobbed using a hob of 110mm outside diameter.

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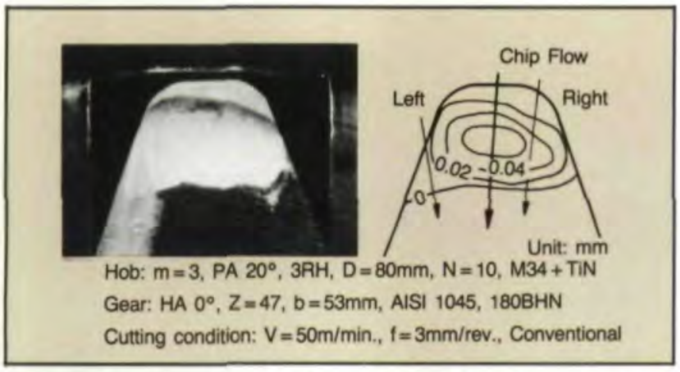


Fig. 9 – Effect of a small outside diameter hob in case of spur gears (Long addendum gear, a=1.5, Blade No. $\bar{3}$, l=32.4m).

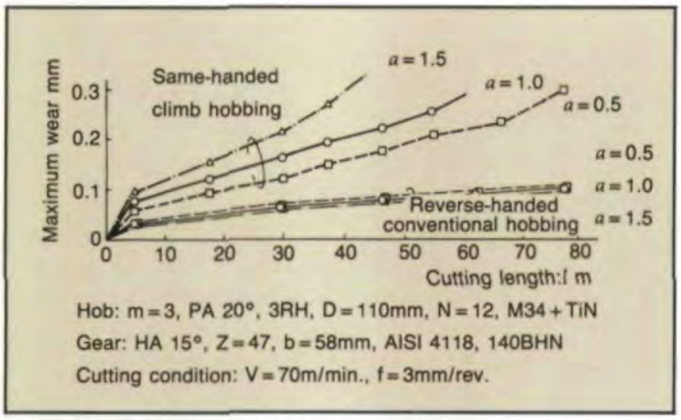


Fig. 10 – Progress of the maximum relief wear (HA 15°).

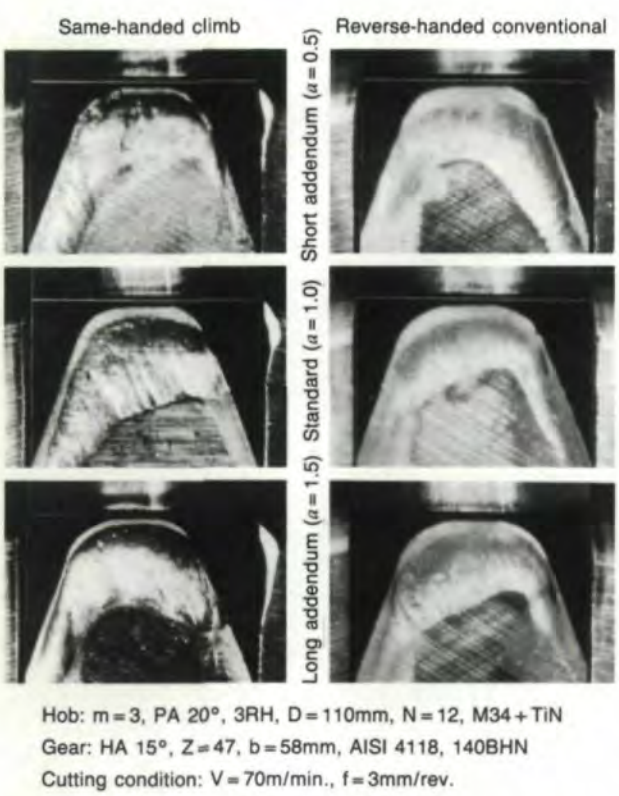


Fig. 11 – Damage to a blade with maximum wear occurred (HA 15°, Blade No. $\bar{6}$, l=45m).

As shown, cutting chips flow straight to avoid breaking down the right corner of the cutting edge.

Fig. 9 shows the damage to blade No. $\bar{3}$ with the maximum relief wear when long addendum gears are conventionally hobbed (cutting length: l=32.4m) using a smaller outside diameter hob of 80mm. The crater wear is not so deep as in Fig. 8 because the cutting speed is lowered (hobbing time is constant), and so the addendum modification coefficient has little influence on it. It is possible to lessen the addendum modification influence and the damage without lowering the gear production efficiency in the case of conventional hobbing with a small outside diameter hob.

Hobbing of Helical Gears

Fig. 10 shows the progress of the maximum relief wear on each hob when profile-shifted gears of a 15° helix angle are cut. The hob is TiN-coated, triple-threaded and of 110mm outside diameter as shown in Table 1. Gear blanks are carbon steel (AISI 1045, 180BHN), cutting speed is 70m/min. and hob feed is 3mm/rev. Judging from this experiment, in the life of a hob used in same-handed climb hobbing, which is now popular, much depends on the addendum modification. On the other hand, it had little influence in reverse-handed conventional hobbing.[7-8]

Fig. 11 shows the damage to a blade No. $\bar{6}$ with the maximum relief wear after 45m cutting length. In the case of the same-handed climb hobbing, the amount of the right corner wear on long addendum gears (C) is the largest. A standard

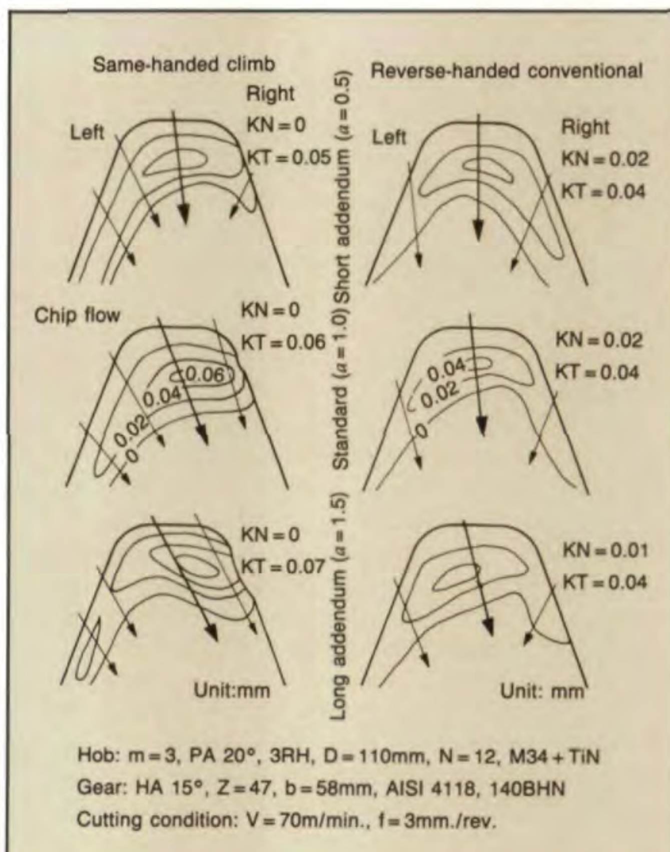


Fig. 12 – Direction of chip flow on each crater (HA 15°, Blade No. $\bar{6}$, l=45m).

gear (B) comes next, and short addendum gears show the least wear. In the case of the reverse-handed conventional hobbing, the amount of corner wear is very small, and it depends little on the addendum modification.

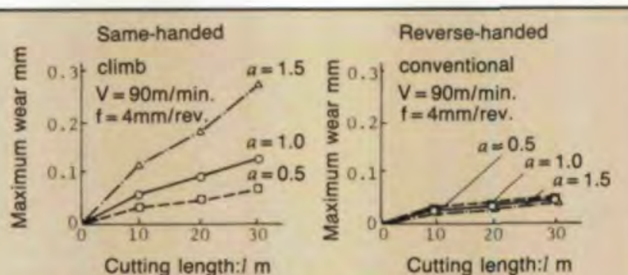
Fig. 12 describes the depth of crater wear and the flow of cutting chips. The crater wear in same-handed climb hobbing grows more rapidly than that in the reverse-handed conventional hobbing, and it extends to the corner of the cutting edge that is broken down. Furthermore, the right side of the cutting edge works little, so that the right corner of the cutting edge is easily broken down by the flow of cutting chips. On the other hand, in the case of the reverse-handed conventional hobbing, the crater wear hardly extends to the right corner of the cutting edge, because the crater wear is not as deep, and the right-side cutting edge works sufficiently to keep the cutting chips away from the cutting edge.

Fig. 13 shows the progress of the maximum relief wear when helical gears (HA 30°, SCM415, AISI 4118, 140BHN) with various addendum modifications are cut at a speed of 90m/min. and a feed of 4mm/rev. using a TiN-coated hob with triple-thread and 110mm outside diameter as shown in Table 1. In the case of helical gears (HA 30°), the addendum modification has much influence on the same-handed climb hobbing, and it has little influence on the reverse-handed conventional hobbing.

Fig. 14 shows the damage of each cutting edge with the maximum relief wear after a cutting length of 30m. The depth of crater wear in helical gears (HA 15°, AISI 1045, 180BHN) is smaller than in Fig. 11, but the right corner of cutting edges are already scooped out, and the cutting edge has retreated because of the crater wear caused by same-handed climb hobbing.

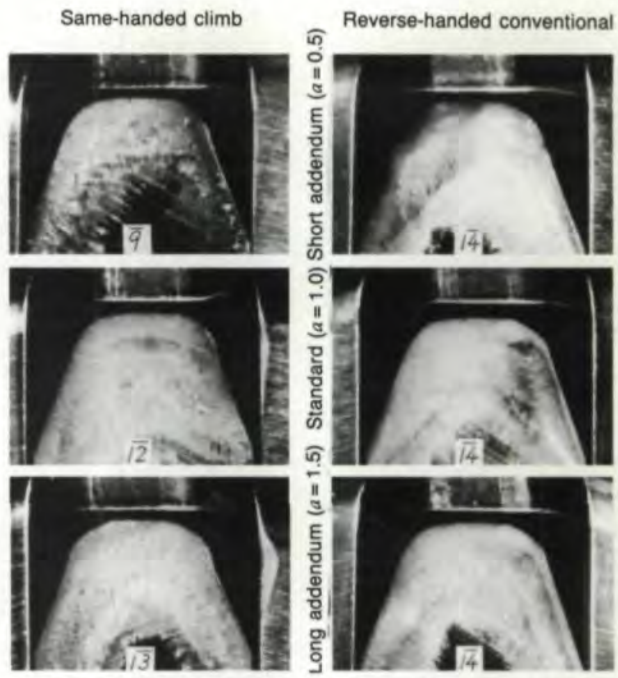
In same-handed climb hobbing, the crater wear is caused by the flow of cutting chips from the top and the left corner of the cutting edge to the right corner, resulting in the retreat of the right corner of the cutting edge. The influence of the addendum modification becomes apparent at the beginning of hobbing, where the cutting edge is breaking down. In this case, the wear of the right corner increases in the following order: short addendum gears (A), standard gears (B) and long addendum gears (C). But in the case of the reverse-handed hobbing, the addendum modification has little influence on the corner wear.

Accordingly, the authors recommend reverse-handed con-



Hob: m = 3, PA 20°, 3RH, D = 110mm, N = 12, M34 + TiN
Gear: HA 30°, Z = 57, b = 30mm, AISI 4118, 140BHN
Cutting condition: V = 90m/min., f = 4mm/rev.

Fig. 13—Progress of the maximum relief wear (HA 30°).



Hob: m = 3, PA 20°, 3RH, D = 110mm, N = 12, M34 + TiN
Gear: HA 30°, Z = 57, b = 30mm, AISI 4118, 140BHN
Cutting condition: V = 90m/min., f = 4mm/rev.

Fig. 14—Damage to a blade where maximum wear occurred (HA 30°, V=90m/min, f=4mm/rev., l=30m).

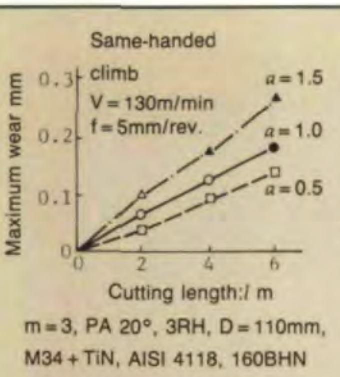


Fig. 15 – Progress of the maximum relief wear (HA 30°).

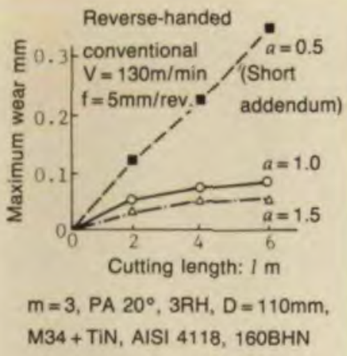


Fig. 17 – Progress of the maximum relief wear (HA 30°).

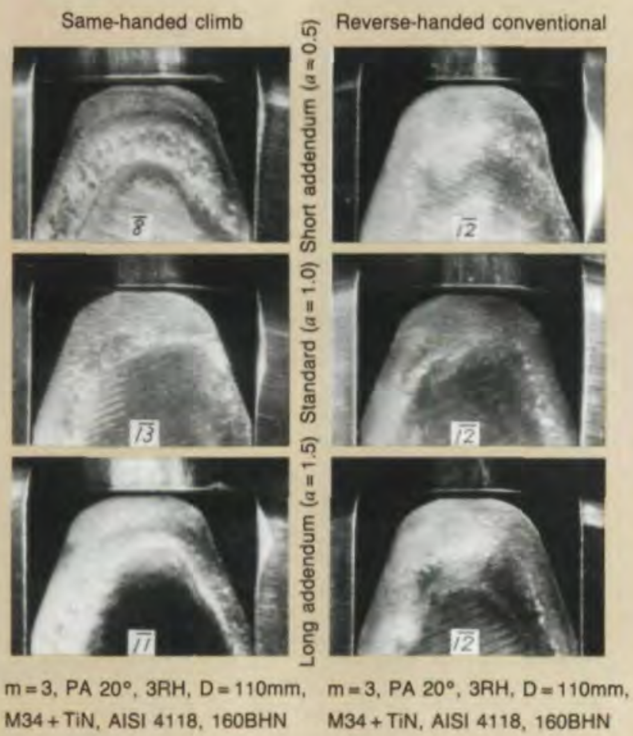


Fig. 16 – Damage to a blade where maximum wear occurred (HA 30°, V = 130, f = 5, l = 6m).

Fig. 18 – Damage to a blade where maximum wear occurred (HA 30°, V = 130, f = 5, l = 6m).

ventional hobbing for shifted helical gears. The depth of crater wear is decreased, and the flow of cutting chips very effectively lessens the corner wear and the influence of the addendum modification.

Hobbing of Helical Gears at High Speed and Feed

Hobbing at a high speed and feed using a multiple-thread hob increases production efficiency, however, the damage to the hob increases.

Fig. 15 shows the progress of the maximum relief wear on helical gears (HA 30°) with various addendum modifications, cut at a speed of 130m/min. and feed of 5mm/rev. in same-handed climb hobbing. Each solid symbol indicates the relief wear caused by the growth and breakdown of the crater wear. When hobbing at a high speed and feed, the amount of wear is great. Especially in the case of profile-shifted helical gears, the maximum relief wear is nearly 0.3mm when only three gears (φ = 6m) were cut.

Fig. 16 shows a comparison of damage to each cutting edge with the maximum relief wear after 6m cutting length. The wear of the right corner increased more rapidly in comparison to Fig. 14 where a cutting speed of 90m/min. and a feed of 4mm/rev is used. In the case of the same-handed climb hobbing for profile shifted helical gears, the cutting conditions, like a cutting speed of 130m/min. and a feed of 5mm/rev., are impossible for practical use.

Fig. 17 shows the progress of the maximum relief wear in reverse-handed conventional hobbing. Under such conditions, there has been little influence of addendum modification. But when the cutting condition is very severe, like a cutting speed of 130m/min. and a feed of 5mm/rev. for short addendum gears, a large amount of wear at the side cutting edge occurred when only three gears (φ = 6m) were cut.

Fig. 18 shows the damage to each blade No. $\overline{12}$ with the maximum relief wear when the cutting length is 6m. Little crater wear occurs in the case of short addendum gears, but facing the cutting surface, the side cutting edge is much constricted, and a large amount of semicircular relief wear occurs on the relief side. However, the side wear has not occurred in the case of long addendum gears. Therefore, the authors calculated the predicted change of each cutting chip for gears with various addendum modifications to find out the cause of wear.

Fig. 19 shows the shape of cutting chips from the right side

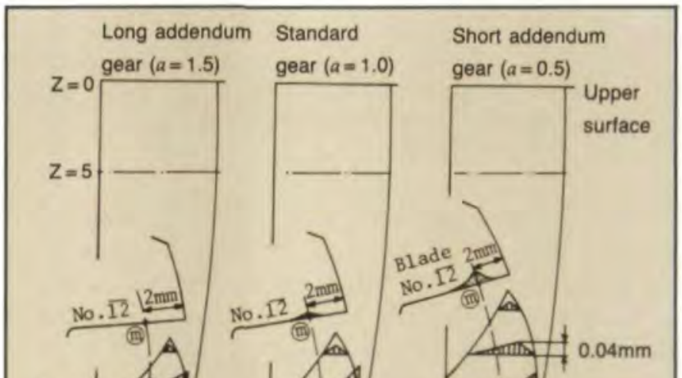
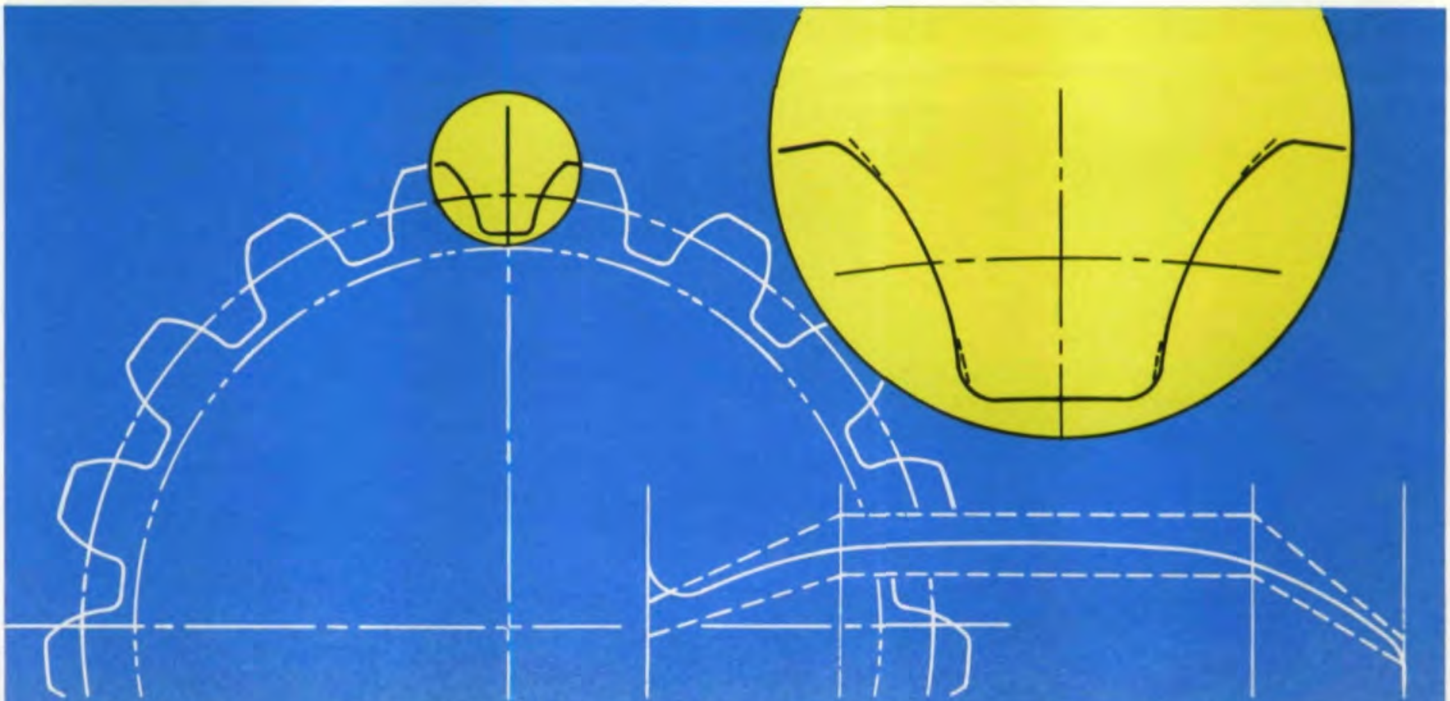


Fig. 19 – Shape of cutting chips from the right side cutting edge in case of reverse-handed conventional hobbing.



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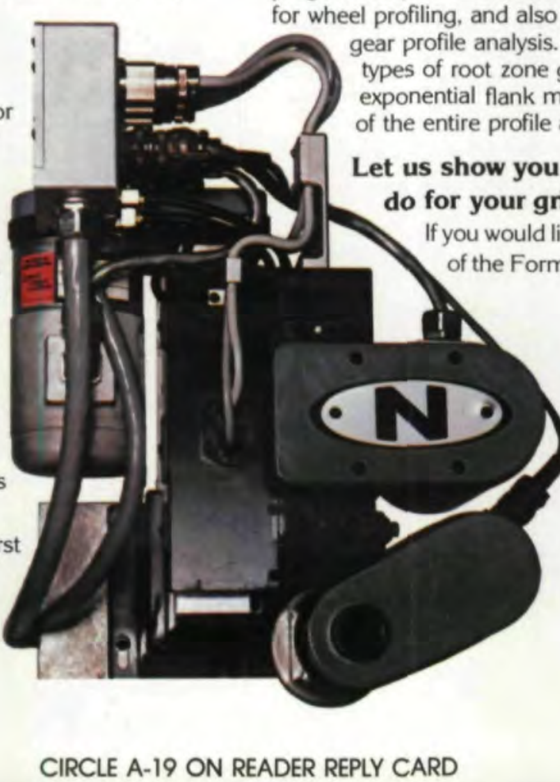

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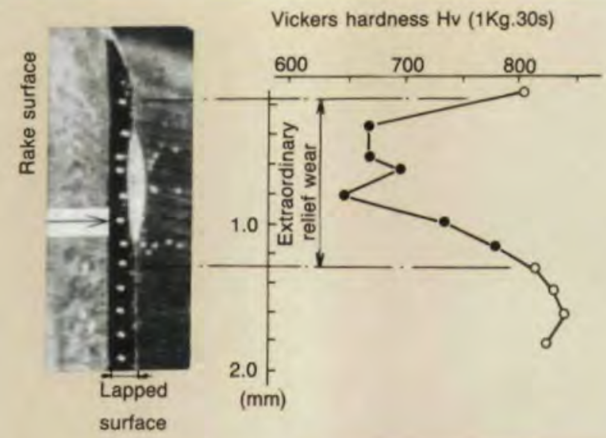
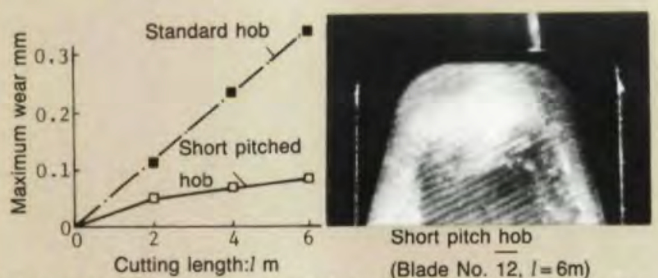


Fig. 20 – (left) Hardness of the right side wear of a blade (Short addendum gear, a=0.5, Blade No. $\overline{12}$).

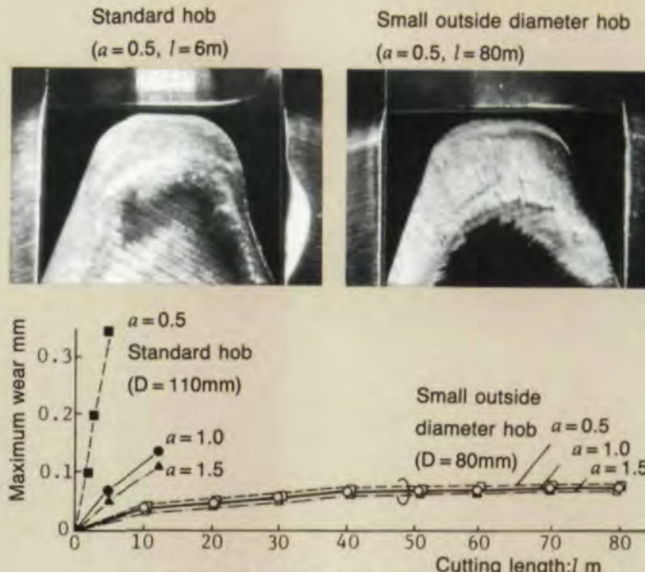


Short pitched hob: m=2.9118, PA 14.5°, 3RH, D=110mm, M34+TiN

Short addendum gear: m=3, PA 20°, HA 30°, Z=57, AISI 4118, 160BHN

Cutting condition: V=130m/min., f=5mm/rev., Reverse-handed

Fig. 21 – Effect of modified pitched (Short-pitched) hob.



Hob: m=3, PA 20°, 3RH, M34+TiN

Gear: HA 30°LH, Z=57, AISI 4118, 160BHN

Cutting condition: n=375rpm, f=5mm/rev.

n: Revolution of hob axis

Fig. 22 – Effect of small outside diameter hob.

cutting edge of blade No. $\overline{12}$ under cutting conditions as shown in Fig. 18, and the trace of the cutting edge ⓜ with the side wear on the gear tooth surface. The encircled portion is the cutting zone for a cutting blade No. $\overline{12}$. The portion of oblique lines shows the thickness of each cutting chip in axial section at 2.5mm intervals. It is clear that the cutting edge ⓜ with the extraordinary side wear is producing the thinnest cutting chip in the reverse-handed conventional hobbing of short addendum gears.

Fig. 20 shows the hardness of the right side wear of blade No. $\overline{12}$ where it is ground to make it smooth using a micro-Vickers hardness tester. As shown here, the area of wear is remarkably softened.

This may be because the cutting edge around ⓜ produces thin chips at a high speed and feed in the reverse-handed hobbing of short addendum gears and then hardly cuts in. It is important to avoid this rapidly growing damage. Therefore, the authors prepared a modified pitched hob and a smaller outside diameter hob for the next experiment to find out the effect.

Modified pitched hob. As Fig. 18 showed, the side wear does not occur in the reverse-handed conventional hobbing of long addendum gears. Accordingly, the authors prepared a short pitched hob for short addendum gears like those for long addendum gears. Fig. 21 shows the progress of the maximum relief wear and the damage on both hobs. A standard hob such as is shown in Table 1 and a short pitched hob for cutting short addendum helical gears were cut at a speed of 130m/min. and a feed of 5mm/rev. using reverse-handed conventional hobbing. In the case of a short pitched hob, corner wear occurs, but there is little side wear.

Small outside diameter hob. Fig. 22 illustrates the progress of the maximum relief wear when profile-shifted gears are cut under the same conditions using hobs of outside diameter 110mm and 80mm in reverse-handed conventional hobbing. In the case of a smaller outside diameter hob, little wear occurs, and there is little influence of addendum modification. It is proven that a short pitched hob and a small outside diameter hob are both effective to lessen the extraordinary side wear which often occurs when profile-shifted gears are cut at a high speed and feed in the reverse-handed conventional hobbing.

Conclusion

The authors have made experiments on hobbing to find out how to lessen the damage to the cutting edge of profile-shifted gears. As a result:

(1) The distribution of crater wear and the direction of chip flow depend on the addendum modification of gears, and they have an influence on each cutting edge which is broken down.

(2) In the case of climb hobbing for spur gears and same-handed climb hobbing for helical gears, addendum modifica-

(continued on page 47)

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(continued from page 18)

tion has great influence, and the corner wear becomes greater when long addendum gears are cut.

(3) In the case of conventional hobbing for spur gears and reverse-handed conventional hobbing, the influence of addendum modification is comparatively small.

(4) Addendum modification has more influence on crater wear as the cutting speed increases.

(5) Therefore, it is true that conventional hobbing with a small outside diameter hob for spur gears, and reverse-handed hobbing with a small outside diameter hob for helical gears, are very effective for lessening hob wear, even when both short addendum gears and long addendum gears are cut. Addendum modification has no influence on it.

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