M-Steel A standard steel with improved machinability

Technical Report Archive

M-STEEL A STANDARD STEEL WITH IMPROVED MACHINABILITY

Ovako has an extensive R&D since many years, an area that now is in an even higher intensity. Some of the R&D work is published in our technical reports.

Due to that Ovako of today has had a number of different company names and used various trade marks we have until now chosen to not have these reports publicly available. However, many of these technical reports contain valid data about material and steel grades that we still promote, but with other names etc.

The following Technical Report from 1990 is about a way of making steel with improved Machinability, developed by Ovako named M-Steel.

Data and processes in this report represent state of art at time of publishing. If not the exact data, at least the principles are in many cases still used and valid. M-Steel is today a registered trade mark by Ovako, where data has been further developed. For our updated description see our home page section; https://www.ovako.com/en/steel-portfolio/ovako-brands/m-steel/

Technical Report 1/1990

M-Steel A standard steel with improved machinability

ISSN 0284-3366

Seppo Härkönen, Kauko Murole
Heikki Nyholm, Martti Paju
Hannu Pöntinen

OVAKO

Table of contents

Steel grade equivalents

EN 10025*	AISI/SAE	B.S.	SS	OVAKO
42 CrMo 4	4140	708 M40	2244	327
34 CrNiMo 6	4340	970/817 M40	2541	356
21 NiCrMo 2	8620	805 M20	2506	152
Fe 52 C	1518	150 M19	2172	520

* EN = European Standard

1. Introduction

Production of speciality components from steel bars invariably involves machining operations. Almost without exception, machine shop practice involves considerable amounts of metal being removed from the bars.
See Fig. 1.

Machining takes a considerable share of the production costs for machine parts. In several cases the cost of machining is significantly higher than that of the steel itself. *See Fig. 2.*

It is possible to influence the costs of machining. The development of machine shop technology and new production philosophies lead to reduced costs and flexibility of production. Furthermore, improving the machining properties of the raw material provides considerable savings potential. In fact, modern machine shop technology requires such a high quality and reproducibility of machinability that conventional steels do not always comply with this.

For over 15 years Ovako has carried out research into the effects of the manufacturing process on the machinability of steel. The general machining techniques of machine shop engineering have been used in the investigations, such as turning, drilling and milling. As a result of these extensive studies, a so-called M-treatment (M=machinability) has been developed; a technique, which will improve the machinability of standard steels. Other important properties of steel, such as strength and heat treatment properties are not affected. M-steels are manufactured in a range of structural, carbon, through hardening and case hardening steels.

The aim of this report is to present information on the results of studies carried out on M-steels. Particular emphasis has been laid on experience from test results achieved in practical machining — in laboratories and in the machine shop industry.

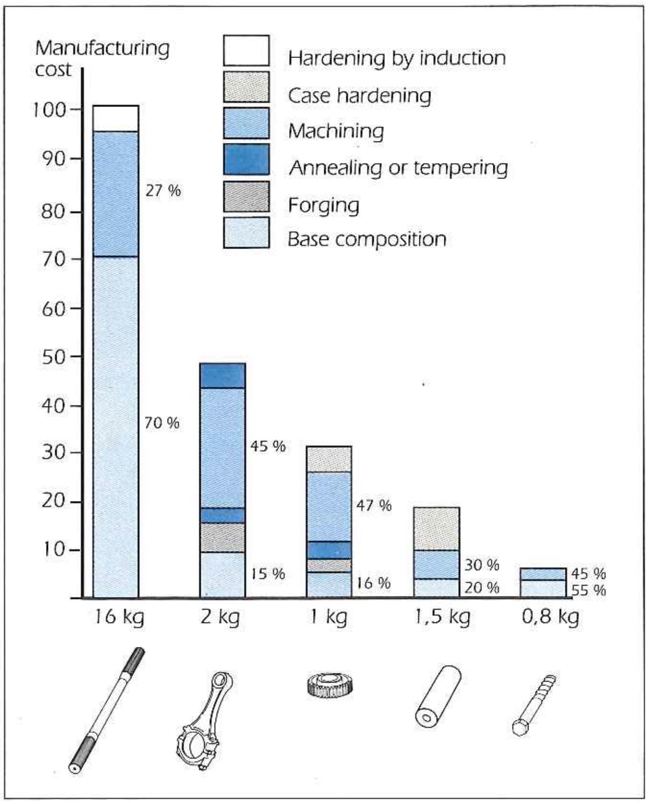


Fig. 2. Manufacturing costs of some products made of special steel.

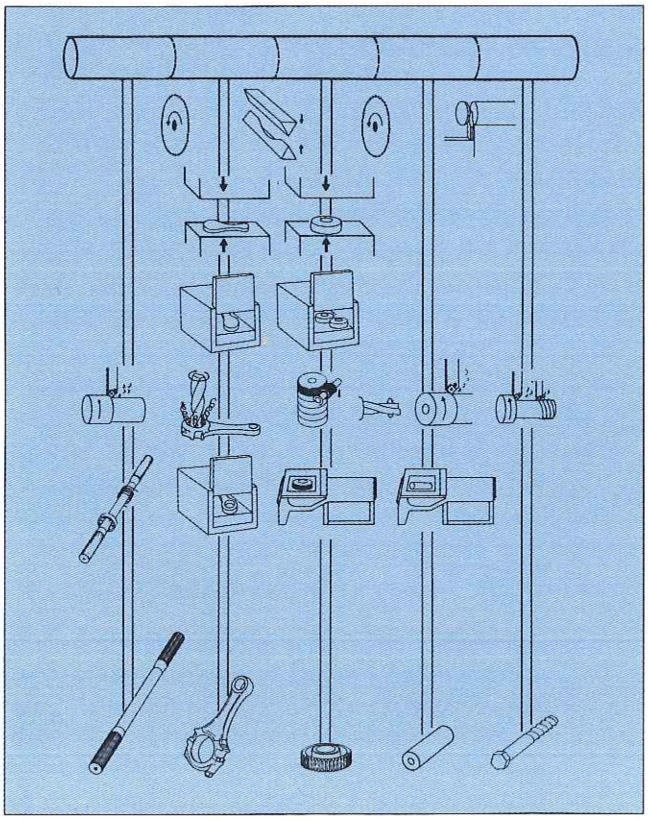


Fig. 1. Manufacturing stages of some products made from special steel.

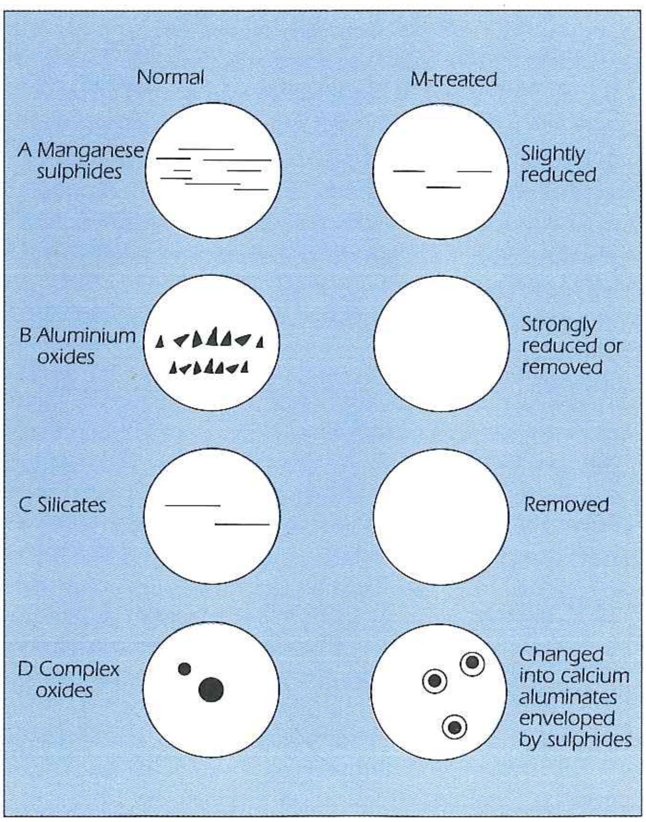


Fig. 3. The effect of M-treatment on non-metallic inclusions in steel.

2. M-treatment

The properties of M-steels are based on the special process of steel manufacture called M-treatment. The machining properties of steel are improved by M-treatment without altering other properties of the steel. The mechanical properties of M-steels are as good as those of corresponding conventional steels. M-steels are produced according to general and customer standards.

In practice, M-treatment consists of metallurgical technology, optimised composition and heat treatment. A quality control test of machinability is also an essential part of M-treatment.

By injection metallurgy, the non-metallic inclusions in the steel are modified to improve the machinability of the steel. The undesirable hard oxide inclusions in conventional steels are changed by the treatment developed for this purpose into softer calcium aluminates enveloped by sulphides. *See Fig. 3.*

These so-called AD inclusions reduce the tool wear in machining due to a decrease in inclusion abrasiveness, and at higher machining speeds they form a protective film on the surface of the tool.

Optimised heat treatment produces the most advantageous microstructure and hardness for machining within the limits permitted by the standard in question. It is very important to obtain the best microstructure for a given steel composition to get the best machinability possible.

M+S-treatment

National steel standards usually restrict the sulphur content in special steels to a maximum of 0.035-0.050 %. By raising the sulphur content to a level of 0.10% in combination with M-treatment, the machinability of M-steel can be further improved for both high machining speeds ("hard metal operations") and low machining speeds ("high-speed steel operations"). The longitudinal mechanical properties of M+S-steel, particularly its fatigue strength, are comparable with those of conventional steels with low and medium hardness. M+S-steels have been succesfully used as substitutes for leaded alloyed steels.

3. Mechanical Properties of M-steel

The mechanical properties of steels depend, among other things, on the alloying, the microstructure and non-metallic inclusions. M-steel differs from conventional steel in its inclusion structure. The mechanical properties of M-steels have been extensively studied both in laboratories and by steel users. The results have been at least as good as those of conventional steels that were included in the comparisons. M-steels have been used for years in the car industry for components with demanding requirements such as gears and shafts.

The static mechanical properties of M-steels, yield and tensile strength, elongation and reduction of area are the same as those of the corresponding conventional steel. Impact resistance is also similar in both M-treated and conventional steels. The dimensioning of components with demanding requirements and which have to endure varying loads is nowadays based on the dynamic mechanical properties, i.e. fatigue resistance. The fatigue resistance of steel depends on many factors, of which strength and inclusion contents are the most significant ones. The following presentation discusses typical results of fatigue tests carried out on M-steels.

Fatigue Resistance

The fatigue resistance of M-steels has been examined at various strength levels by using smooth bars and axial tension-compression or torsional bending load. *See tables 1* and *2*. The fatigue resistance of M-steels has been studied by using notched specimens at The Swedish Institute of Metals Research (Institutet för Metallforskning) in Stockholm. *See table 3.*

The results presented in the tables demonstrate that the fatigue strength of M-steel at the tensile strength level of 800-1600 N/mm^2 is the same as that of corresponding conventional steels. Increasing the sulphur content to 0.1 % does not reduce the longitudinal fatigue strength of M-steel. There is no difference in the fatigue strength of conventional steel and M-treated steel under the influence of notches either.

	Conventional Steel S max 0.035 %	M-Steel S max 0.035 %	M+S Steel S approx. 0.10 %
R_m N/mm^2	800-970	883-971	916
$\sigma\mu/R_m$	0.41- 0.46	0.42- 0.46	0.45

Table 1. Axial tension-compression (R=-1), smooth bars, maximum load cycles 10^7. Tempered steel 42 CrMo 4, R_m approx. 900 N/mm^2 (Ovako)

	Conventional Steel S max 0.035 %	M-Steel S max 0.035 %	M+S Steel S approx. 0.10 %
R_m N/mm^2	1530 -1640	1580 -1640	1390 -1400
$\sigma\mu/R_m$	0.31- 0.36	0.31- 0.34	0.38- 0.39

Table 2. Torsional bending (R=-1), smooth bars, maximum load cycles 10^7. Tempered steel 42 CrMo 4, R_m approx. 1400-16 N/mm^2 (Ovako)

	Conventional Steel S max 0.035 %	M-Steel S max 0.035 %
R_m N/mm^2	1530 -1640	1580 -1640
$\sigma\mu/R_m$	0.31- 0.36	0.31- 0.34

Table 3. Axial tension-compression (R=-1), notched bars, maximum load cycles 10^7, Tempered steel 42 CrMo 4, R_m approx. 1300-1400 N/mm^2 (The Swedish Institute for Metals Research)

The fatigue strength of carburizing steels has, furthermore, been studied both in the tooth bending of gears, *Figure 4a,* and for rolling contact, *Figure 4b.* The test materials had been case hardened. Also, according to these studies, the fatigue strength of M-steel is as good as that of conventional steel with the same content of sulphur. A reduced sulphur content improves the fatigue strength somewhat in the case of tooth bending, because the bending is transversal in regard to the rolling direction.

Studies have also been carried out on finished components. An example of this is the fatigue test of drive shafts in lorries, carried out by Saab-Scania. The material was tempered steel 42 CrMo 4 in hardened and tempered condition and with an induction hardened surface. The maximum load cycle used was 8×10^5. According to the test results there was no difference between the fatigue strength of the M-steel and that of the conventional steel.

4. Machinability of M-Steel

4.1 Definition of Machinability

By machinability we mean the relative ease of producing items from a certain material by machining techniques forming chips. Consequently machinability is the common property of both the machining technique in use, i.e. the machine and the tool, and the material to be machined.

The machinability of steel can be assessed by the tool wear, the quality of finished surface, the chip form and the cutting forces. *See Fig. 5.* It depends on the techniques used which of these factors is the most important aspect of machinability. More often than previously, as a result of developments in machine shop technology, the most important criterion of machinability has become the small difference in machinability between different production batches (shipments).

4.2 Tool Wear

One method of assessing the machinability of a certain material is to measure the wear rate of the cutting tool. The wear rate of the tool is dependent on the prevailing wear mechanisms, of which the most important ones are: adhesive, abrasive, oxidation and diffusion wear, and plastic deformation. The prevailing wear mechanism, again, is primarily dependent on the temperature of the contact surface of the tool and the chip, and, consequently, on the machining speed, feed, depth of cut and the properties of the tool and material to be machined. While machining a certain material by different techniques (e.g. carbide tool turning, high-speed steel milling and drilling), the machining conditions and factors affecting the tool wear vary when changing from one operation to another.

M-treatment reduces tool wear in two ways: Firstly, the oxides which cause abrasive tool wear are totally removed from the steel by M-treatment, and complex oxides are transformed into softer calcium aluminates

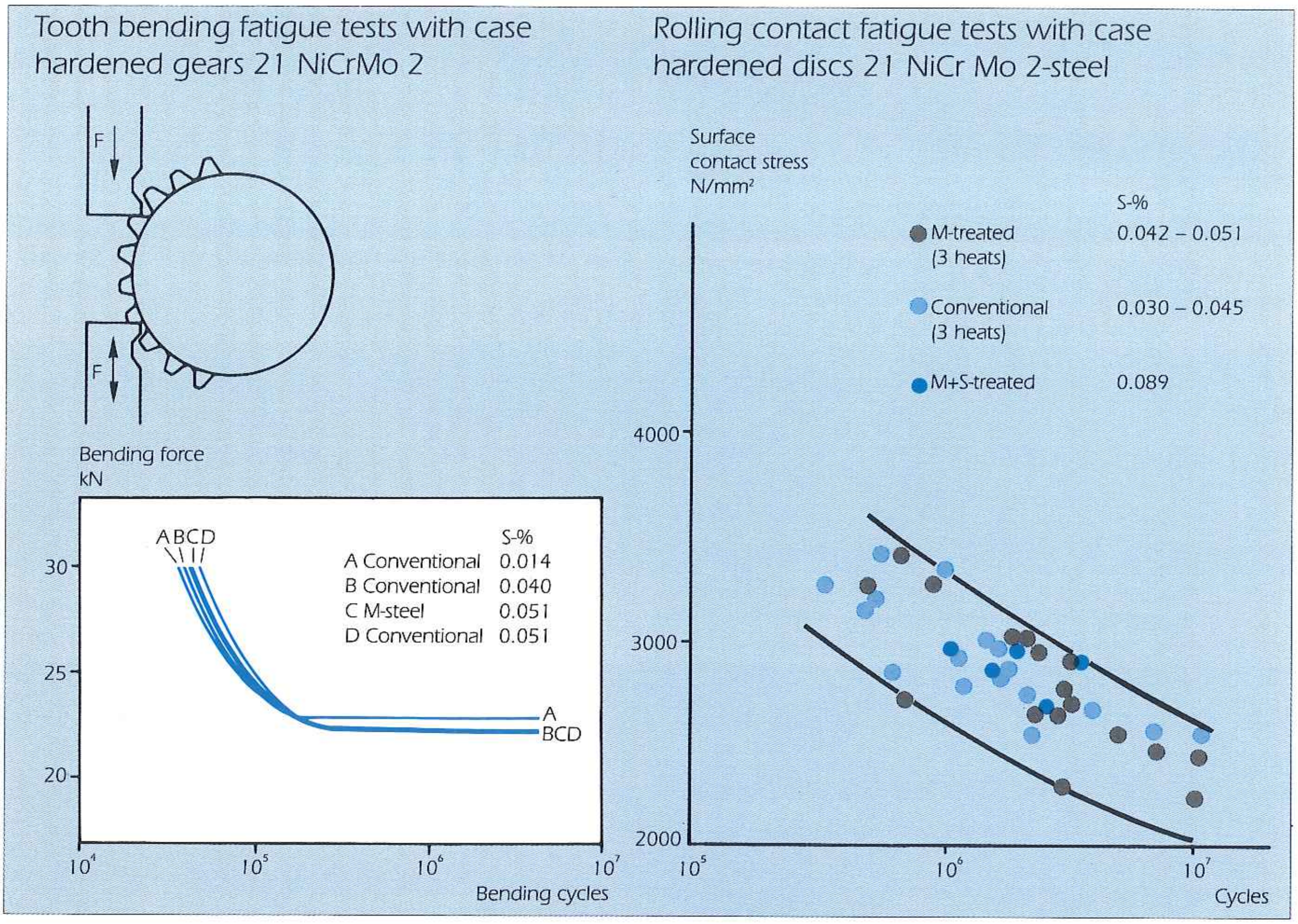


Fig. 4. The effect of M- or M+S-treatment on the fatigue resistance of carbon steel in a) tooth bending of gears and b) a rolling contact test.

which are furthermore enveloped by a (Ca,Mn)S-film. Secondly, in favourable conditions, these calcium-aluminate-sulphide complexes form a "lubricating" film on the face of the machining tool effectively preventing crater wear of the tool face. (*See Figs. 6 and 7*).

During carbide tool machining of M-steels, unlike conventional steels, the flank wear of the tool is almost always the wear form determining the tool lifetime. This property of M-steels is of significance, because intensive crater wear weakens the machining edge and may lead to sudden tool fracture. Practical machining tests and laboratory studies have, in fact, demonstrated that the number of tool breakages has been reduced when changing from the use of conventional steel to the use of M-steel.

4.2.1 Turning

When investigating the machinability of steels the technique mostly in use at Ovako is the turning test in accordance with the ISO 3685-1977 standard (*see Table 4*). When carrying out comparisons of machinabilities of steels, a coated carbide tool of the type P15 is normally used, but other types of carbide tools, cermets, ceramic and high-speed steel tools have also been employed in turning tests.
In measuring the machinability of steels, the speed of V15 specified in the test is used, whereby it takes 15 minutes of turning until the wear of the machining tool has reached the wear criteria set by the standard.

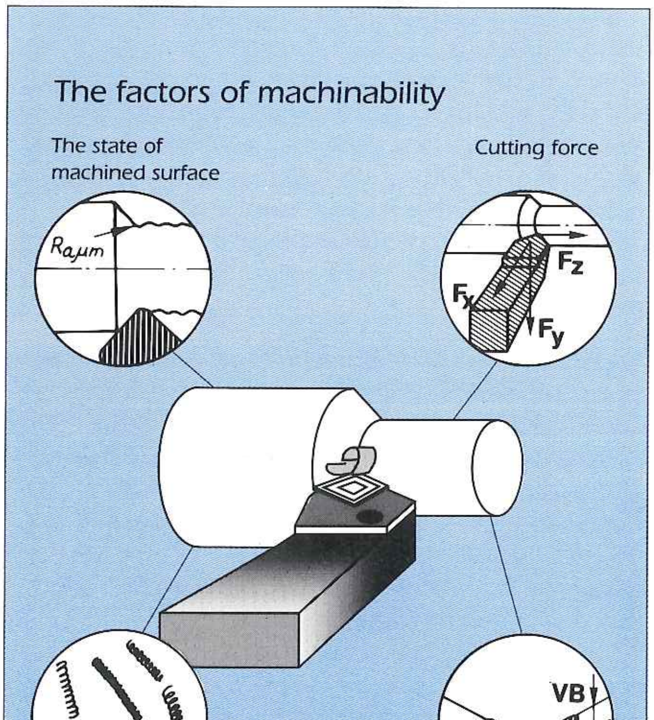


Fig. 5. Factors determining machinability.

Turning with a Carbide Tool

The machinability of steels has been under investigation at Ovako since the late 1960's. A large number of steels of various types and origins have been studied during this time. Part of the results are compiled in *Figure 8.* The curves in the figure are based on a regression analysis of test results on conventional steels, M-steels and sulphurized M+S-steels (54, 98 and 12 heats) which have been studied. The cross-hatched areas represent a typical spread of results for the machinability of various types of M-steel. The conventional steels studied were produced by Ovako and by other steel manufacturers.

As is shown in *Figure 8,* the V15-values of M-steels at all levels of hardness are on an average about 30% higher than those of corresponding conventional steels. By sulphurization i.e. by raising the sulphur content of the steel from the usual 0.03 % level to around 0.1 %, the machinability of steels can be further improved by approximately 25 %.

The microstructure of steel has only minor implictions for carbide turning; there is no substantial difference in the machinability of martensitic quenched and tempered steels and in ferritic-pearlitic microalloyed steels. The carbide machinability of steels during turning is slightly impaired, however, when the content of carbon or alloying elements in the steel is increased, which is the reason why the structural steel Ovako 520

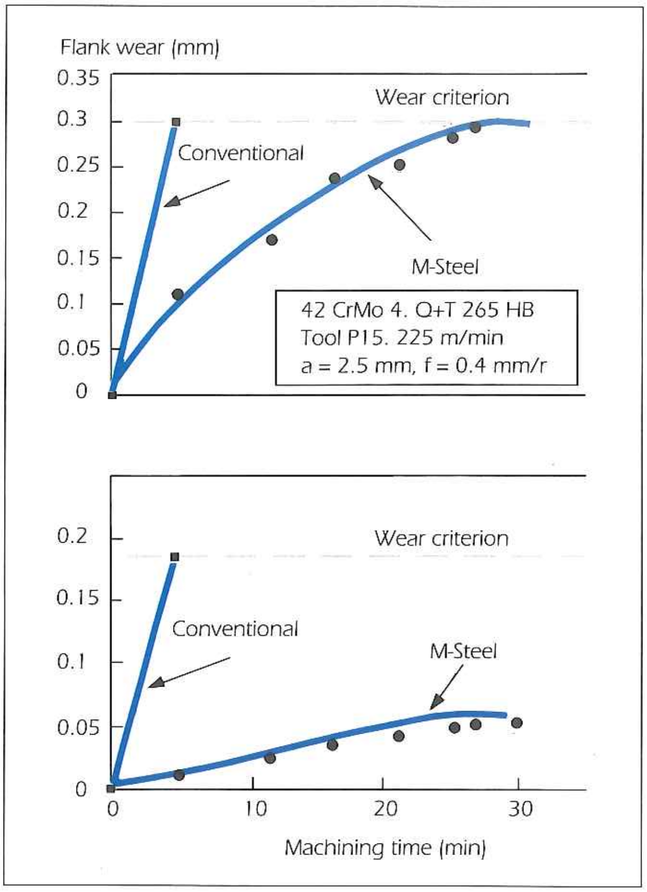


Fig. 6. The effect of M-treatment on tool wear in carbide tool turning.

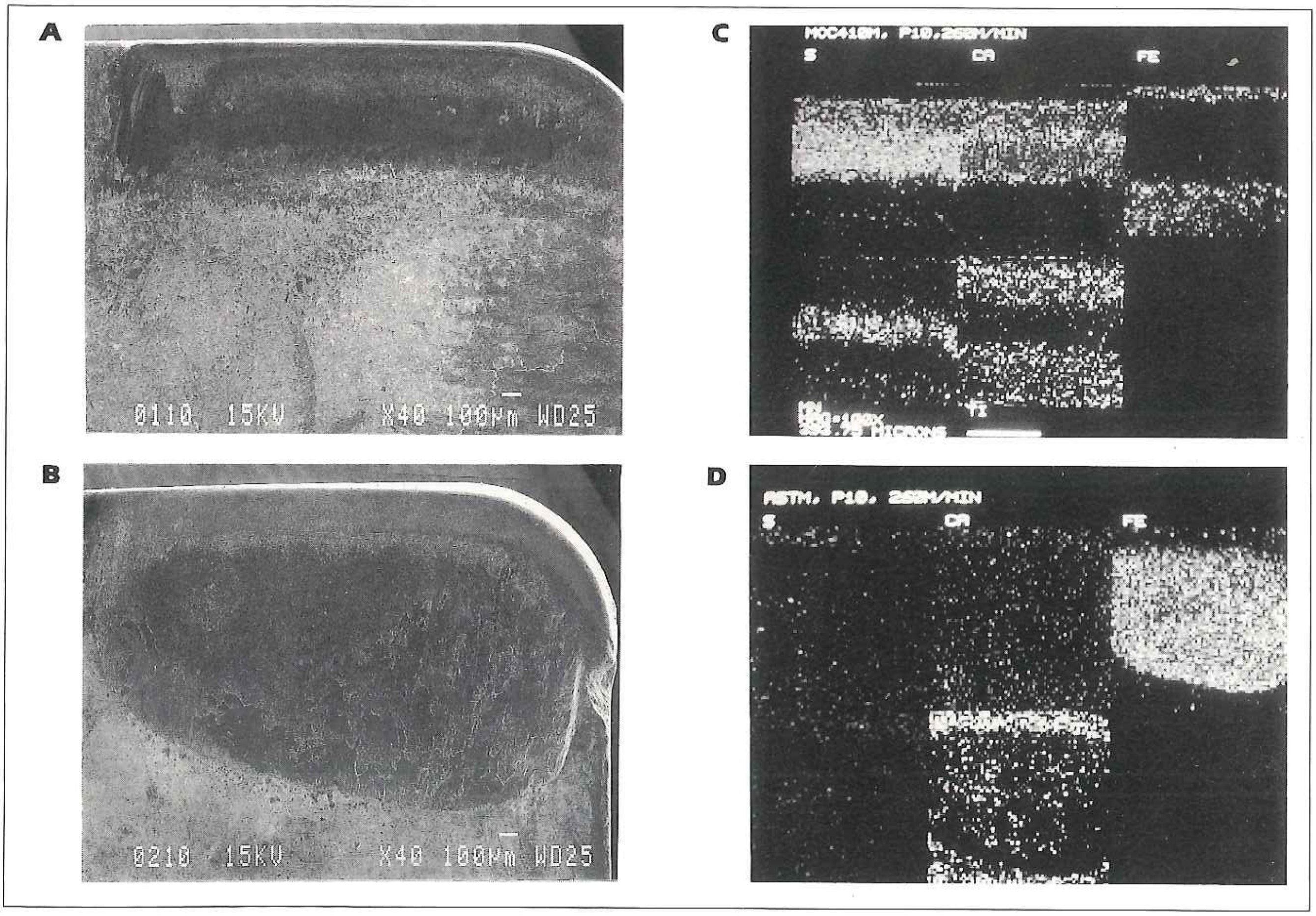


Fig. 7. Wear of tool face type P10, when it has been used for machining of A) M-steel 42 CrMo 4 M 260 m/min, 5.0 min, or, B) conventional steel 42 CrMo 4, 260m/min, 0.5 min. C) (Mn.Ca) S-protecting film on the tool face in figure 7a, and D) some steeel adhering to the crater wear area of the tool in figure 7b.

is on an average about 10 % easier to turn than carburizing steels of corresponding hardness. Among other alloying elements in steel, titanium is the most detrimental.

Turning with Ceramic and Cermet Tools

Turning tests carried out on M-steel have confirmed the opinion, documented in literature, that ceramic tools are not suitable for machining of soft steels, i.e.

Test	Turning ISO-3685-1977	Milling SFA/Volvo	Drilling Ovako /The University of Technology in Lappeenranta
Tools	Cemented carbide P10, 15, 20, 25 oxide ceramic, mixed ceramic and cermet, high-speed steel	High-speed steel	High-speed steel ø 7.5 mm
Feed mm/r	0.4	0.1	0.19
Cutting depth, mm	2.5	1.0	—
Cutting lubricant	none	emulsion (Cimcool)	emulsion 3.7 l/min
Tool life criteria	flank wear VBavg=0.3 mm VBmax=0.6 mm crater wear KT=0.18 mm	VB=0.7 mm	increase of 100 % in torsion or 50 % in feed force
Test result	Taylor-diagram V15 (m/min)	SFA-index K-value	Taylor-diagram V2000 (m/min)

Table 4. Machining tests used at Ovako, Imatra.

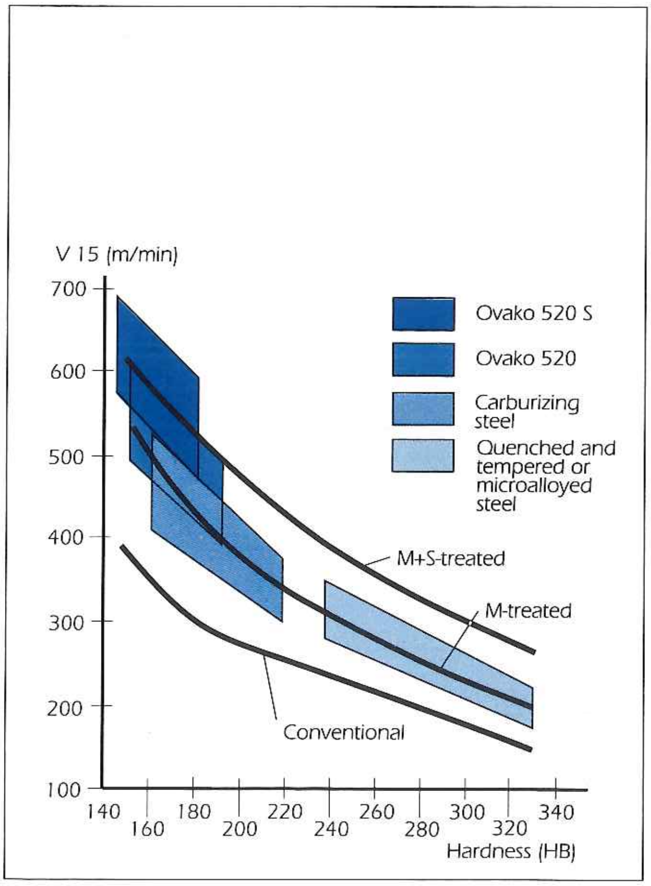


Fig.8. The variation in carbide turning result as a function of steel hardness for different steels.

< 250 HB. Turning tests carried out on the structural steel Ovako 520, in which both oxide and mixed ceramic tools were used, were in part hindered by tool breakages, and the tool life remained shorter than in cases where cemented carbide tools were used.

However, considerably higher cutting speeds can be used when turning hard steels (e.g. quenched and tempered, microalloyed steels) with ceramic or cermet tools than with cemented carbide tools. When using oxide ceramic tools, M-steel is only slightly more machinable than conventional steel (*see Fig. 9a*), but for machining with mixed oxide ceramic and cermet tools, M-steels wear the tools to a significantly lesser degree than conventional steels (*see Figs. 9b, 9c*). This is due to the fact that the TiC content in the mixed ceramic and cermet tools makes it possible for a stable protective film to be formed on the tool face, which, in turn, allows almost a doubling of machining speeds in the turning of M-steels. There were also less sudden tool breakages in turning with mixed ceramic and cermet tools than with oxide ceramic tools.

4.2.2. Milling with a High-Speed Steel Tool

Ovako uses the SFA test, developed by Volvo, when studying milling with high speed steel.
(*see Table 4*). In the test, milling is carried out with a high speed steel tool until the flank wear of the tool has reached the value of VB=0.7 mm. When the volume of

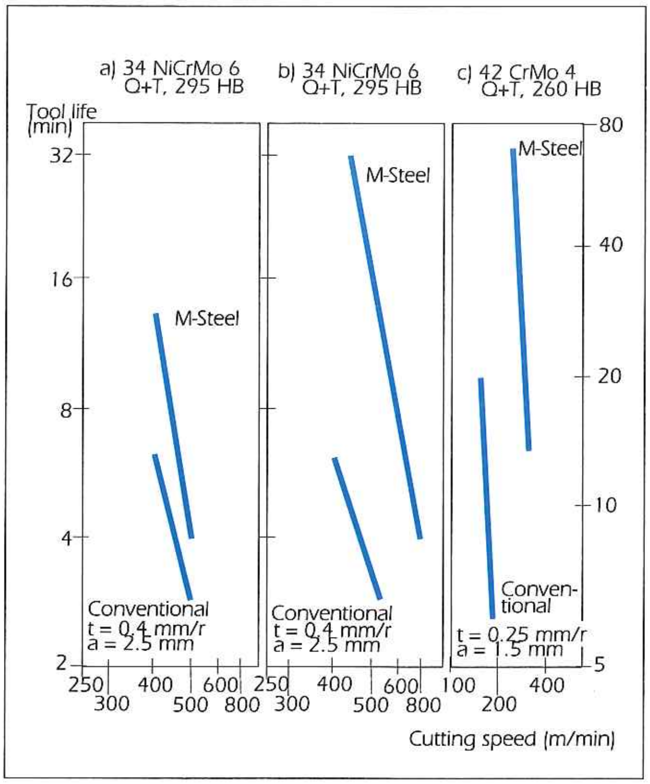


Fig. 9. A comparison of the machinability by turning of M-steel and conventional steel using a) oxide ceramic, b) mixed ceramic, and c) cermet tools.

material removed by each individual tool is inserted in a special SFA diagram (double logarithmic) as a function of the cutting speed the machinability (K-value) of the material can be read on the reference line of the diagram. This index gives a measure of the machinability by milling of the material compared with resulphurized free machining steel (K-value = 100) (*See Fig. 10*). The reference line corresponds to 22 minutes of effective machining time. The abrasive and adhesive wears dominate above the line. Below the line, i.e. with high cutting speeds, the high temperature mechanisms (diffusion, plastic deformation and softening) determine the tool life.

Unlike in carbide turning, M-treatment does not affect the machinability of steel in the SFA-test (*see Fig. 11.*) if K-value is used as machinability index. The regression line in Figure 11 illustrates the average dependence of the K-value on the hardness of steel in both M-steels and conventional steels (78 heats in all). The positive effect of sulphurization on machinability is even clearer in HSS-milling than in carbide turning. Furthermore, *Fig. 11* shows the strong effect of carbon content on milling. Low-carbon steels, IMACRO and BCM 115, are significantly easier to mill than quenched and tempered, microalloyed steels with corresponding hardnesses but with higher contents of carbon, whereas ferritic-pearlitic microalloyed steels are somewhat easier to mill than quenched and tempered steels with corresponding hardnesses.

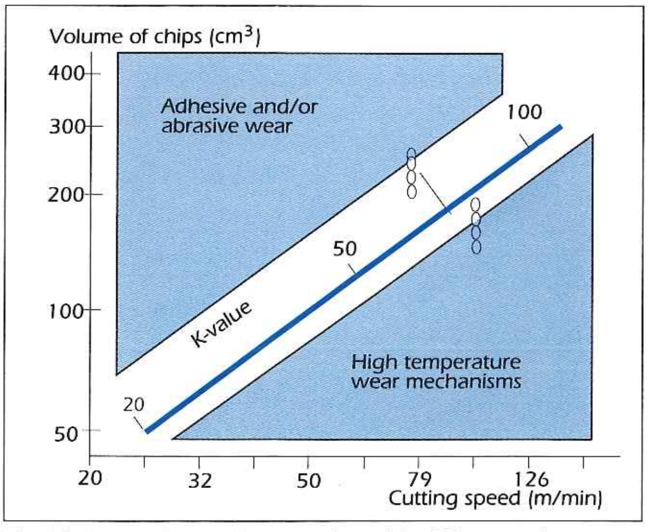


Fig. 10. Presentation and interpretation of the SFA-test results.

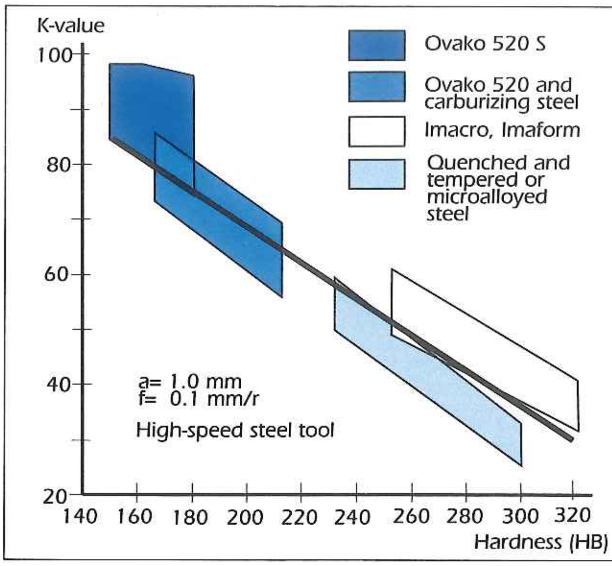


Fig. 11. The effect of hardness on the K-value obtained in the SFA-test.

Thus, according to values in the SFA-test, there is no difference between M-steel and conventional steel. At low machining speeds, however (*see Fig. 12*), i.e. well above the reference line, the tool lifes obtained with M-steel are significantly longer than those obtained with conventional steel. This phenomenon is in all probability due to the character of the SFA-test. The lower degree of abrasiveness of the calcium-aluminates characteristic to M-steel is not revealed until lower machining speeds are used at which both abrasive and

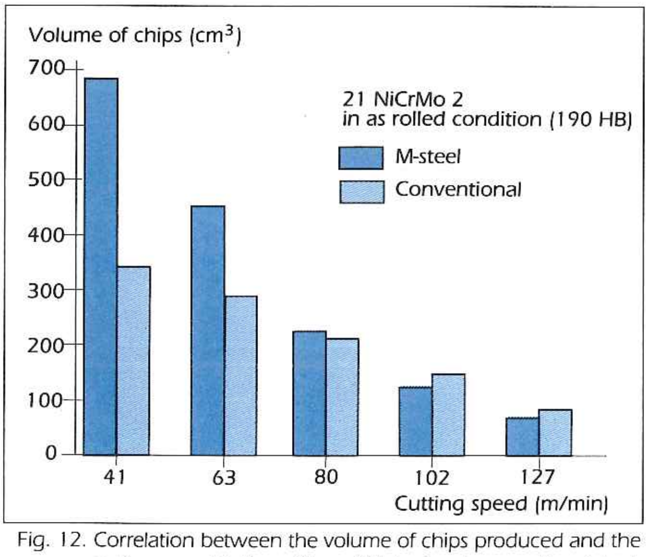


Fig. 12. Correlation between the volume of chips produced and the cutting speed in the milling of M-steel and conventional steel.

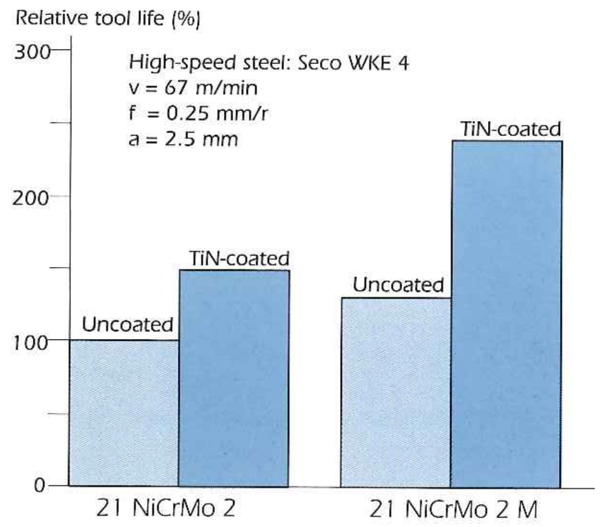


Fig. 13. A comparison of the machinabilities of M-steel and conventional steel in turning tests carried out with TiN-coated and uncoated high-speed steel tools.

adhesive wear are predominant. Field tests carried out by steel users reveal the same phenomenon; tool wear with M-steel is lower at the machining speeds used in practice.

The uncoated high-speed steel tool used in the SFA-test also contributes to the result. Turning tests carried out with TiN-coated and uncoated high-speed steel tools

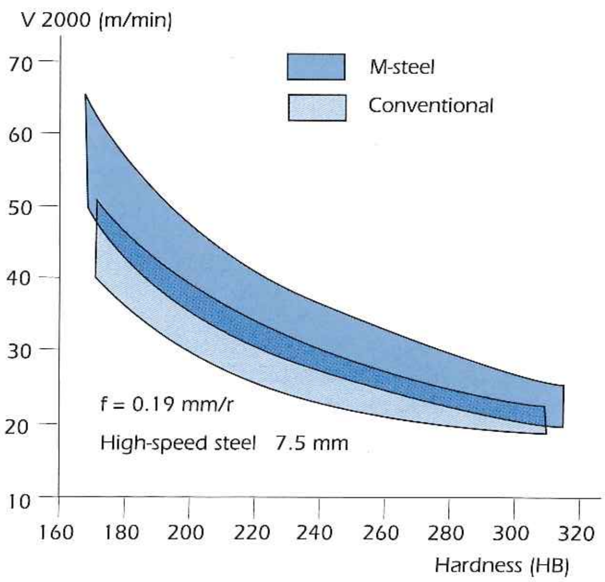


Fig. 14. The effect of hardness on the machinability of M-steels and conventional steels in high-speed steel drilling.

have demonstrated, in accordance with the SFA-test results, that M-steel is only slightly more machinable with an uncoated tool than conventional steel is. TiN-coated tools will give an about 50 % longer tool life in the turning of conventional steel, but the increase in tool life is nearly 150 % with M-steel (*see Fig. 13)*. This phenomenon is due to the protective film which forms on the TiN-coated, but not on the uncoated tool face in machining of M-steel.

4.2.3 High-Speed Steel Drilling

Since there is no standard drilling test for the machinability of steel, Ovako has developed its own high-speed steel drilling test in co-operation with The University of Technology in Lappeenranta (*see Table 4, page 8*), which is used in comparisons of steels and in support of the development work.

Compared with, for instance, turning or milling, drilling is, by its character, clearly a more complicated machining operation, in which, among other things, the chip form is of great significance. The scatter of test results is, consequently, also much wider than in turning. *Figure 14* shows a selection of 78 drilling test results produced with M-steel and conventional steel. One of the key properties of the material regarding drilling, as well as other machining operations, is the hardness of steel. M-treatment improves the drilling of steel by an average of 10-20 %, which is probably due to the lower degree of abrasiveness of the inclusions in the M-steel. Increased sulphur content also has a strong positive effect on the drilling of steel.

4.2.4 Other Machining Operations

Other machining techniques, such as sawing, threading etc., require a definition of machining parameters best suited to each steel, which is why these techniques are not used in routine studies. Ovako has, however, developed a CNC-test for test purposes, in which the machining of the testpiece includes drilling with a carbide tool and a high-speed steel tool, finish turning and forming with carbide tool, grooving with a high-speed steel tool, and an external threading and cut off with a carbide tool. Approximately 200 test-pieces are produced, and the wear of the tools is measured.

The main purpose of the tests carried out has been the identification of the most suitable machining parameters for different M-steels, but these tests have also clearly revealed the superior machinability of M- and M+S-steels. (*See Fig. 15*).

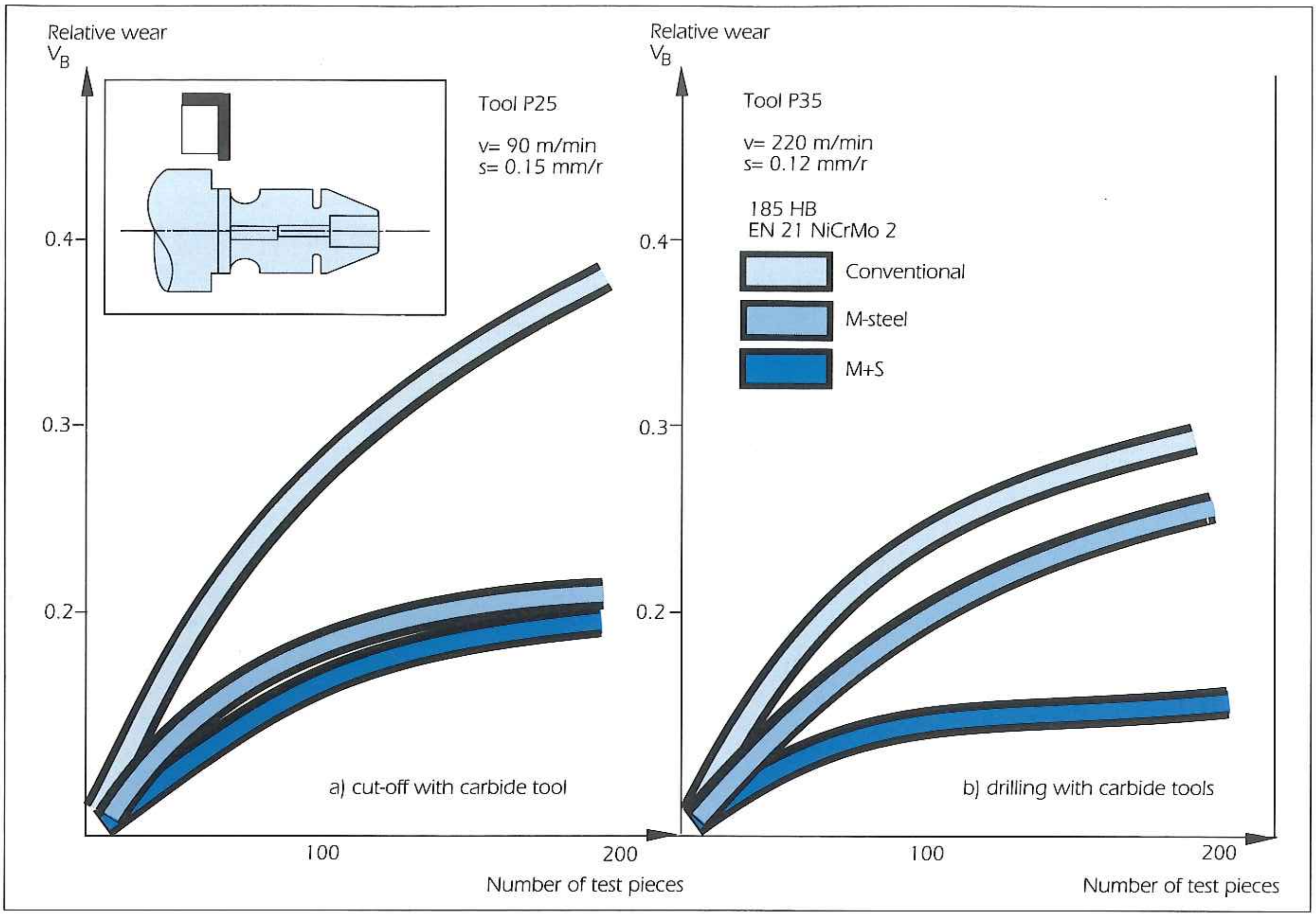


Fig. 15. Wear of the machining tool as a function of the number of test pieces produced in a CNC-test at Ovako Steel.

4.3 Surface Quality

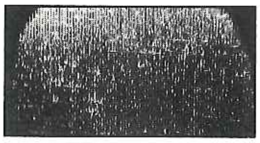
The surface quality produced in the finishing operations is an important factor in assessment of the machinability of steel. The surface quality depends not only on the properties of the material, but also on the machining operation, i.e. tool material and tool geometry, machining parameters, machining lubrication etc.

The surfaces produced with M-steels are generally of a higher quality than those produced in corresponding conventional steels. No apparent physical reason for this has been found. It has been observed, however, that good surface quality has been achieved with M-steels at machining speeds where the formation of a built-up-edge usually considerably impairs the surface quality. A test carried out on soft carbon steels provides an example of this. *See Fig. 16.*

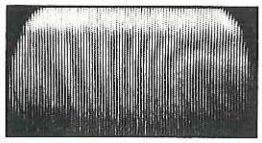
An increase in the machining speeds usually has a positive effect on the surface finish. Higher machining speeds can be used with M-steels, thereby improving the surface finish.

Influence of M-treatment on the surface finish

- Test material: 20 MnCrS 5, annealed 150 – 170 HB
- Cutting data: Carbide turning, nose radius of the tool 0.8 mm
- Examples of the surface profiles



Conventional



M-treated

Cutting speed 60 m/min. Feed 0.13 mm/r

- $R_a$value

Treatment	$R_a$value µm 60 m/min 0.13 mm/r	60 m/min 0.27 mm/r	100 m/min 0.13 mm/r	100 m/min 0.27 mm/r
Conventional	1.5	5.7	1.9	5.8
M-treated	1.4	8.4	1.9	4.8

- Uniformity of the surface

Treatment	Uniformity: poor, fair, good, very good 60 m/min 0.13 mm/r	60 m/min 0.27 mm/r	100 m/min 0.13 mm/r	100 m/min 0.27 mm/r
Conventional	poor	fair	fair	good
M-treated	good	good	very good	good

Fig. 16. The effect of M-treatment on the roughness and uniformity of surface quality produced by finish turning.

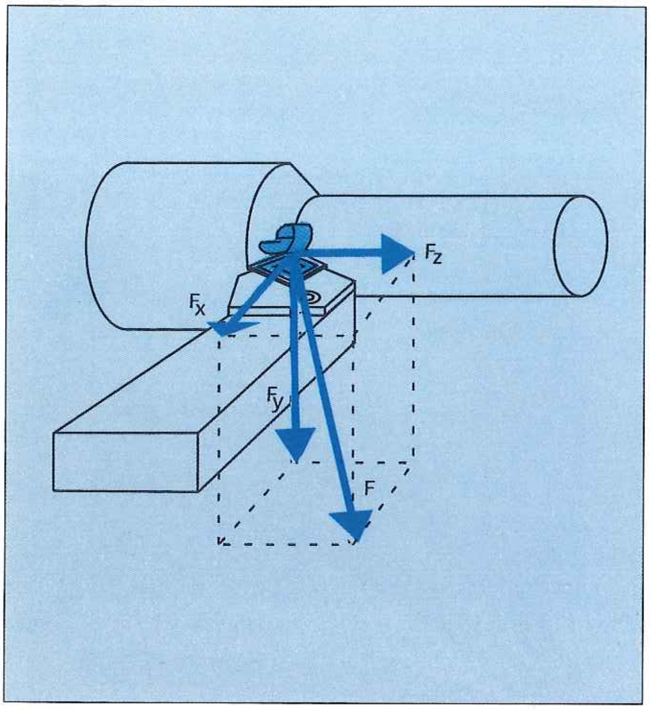


Fig. 17. Forces applied to the machine tool in turning: F = total machining force, Fy = principal machining force, Fz = feed force and Fx = radial force.

4.4 Cutting Forces

The level of cutting forces is one criterion of the machinability of steel. The cutting forces are greatly dependent on machining parameters, such as feed and depht of cut. Consequently, one most fre-quently speaks of specific cutting force, which in practice implies the cutting forces in relation to the theoretical cross sectional area of the chip. Furthermore, the total cutting forces can be divided into components, i.e. principal cutting force, feed force and radial force. *See FIg. 17.*

The cutting forces have been found to be as much as 10-20 % lower for M-steels compared with corresponding conventional steels. The difference is greatest in the feed force, which is probably due to the lubricating film which is formed on the tool face in the machining of M-steel.

4.5 Chip Form

The significance of chip form as a criterion of machinability has grown together with the increased application of automation. Long chips may cause interruptions in production which can only be handled by manual intervention.

The most effective way of influencing the chip form is through tool geometry. Among carbide tool inserts there are a large number of different "sintered chip breakers". Generally, a certain tool geometry is recommended for a certain feed and cutting depth.

Besides tool geometry, machining parameters, particularly feed and cutting speed also affect the chip form. It can be said, generally, that the higher they are, the shorter the chips will be.The steel will also affect the chip form. A steel manufactured according to a certain standard may at times produce long chips with a certain tool and machining parameters, and short chips at other times. The reason may be, for instance, differences in sulphur contents and in micro inclusions. The analysis, micro structure and micro inclusions are controlled in M-steels, whereby the best possible chip form in relevant conditions is achieved, and the variation in chip form is minor.

4.6 Uniformity

The importance of reproducibility in machinability has grown together with increased automation, because the machinability has to be reliably predicted. This includes all previously mentioned contributing factors of machinability, i.e. tool wear, cutting forces, surface quality and chip form. It is essential that the manufacture takes place with correctly chosen machining parameters without disturbances.

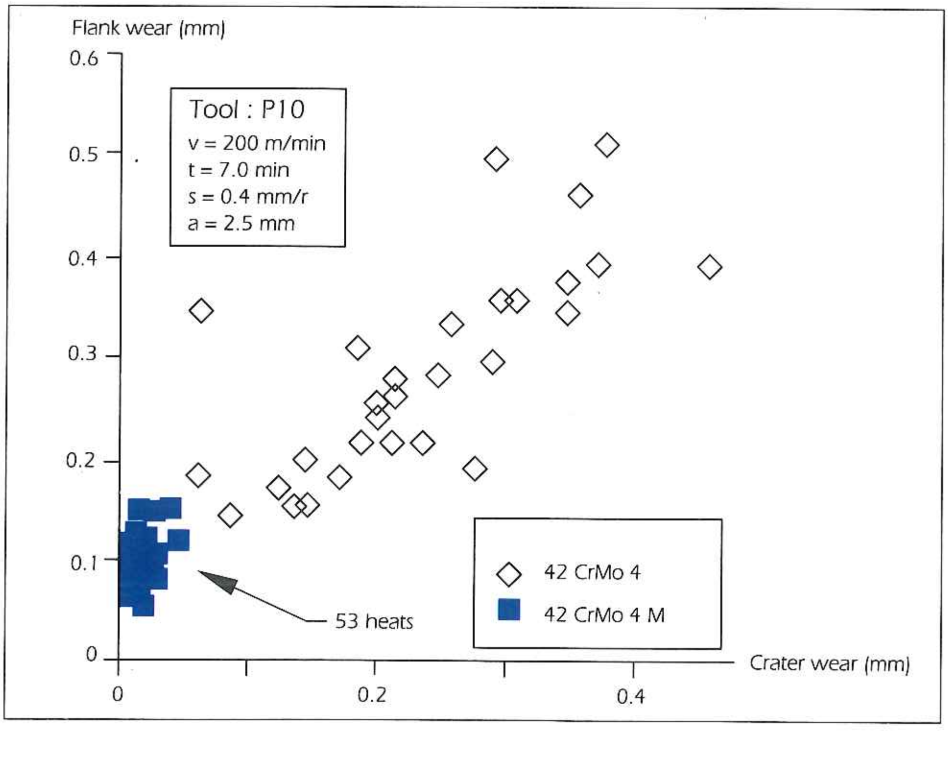


Fig. 18. The spread of tool wear in machinability tests with M-treated and conventional steel.

In the manufacture of M-steel, factors affecting the machinability are closely controlled with the aim of better and more uniform machinability. The machinability test is an important part of the M-steel concept. Extensive statistics on machinability tests have provided the basis for correct planning and control of manufacturing parameters. As a result, the variation in machinability of M-steel from one heat to another is less than that of conventional steel. *See Fig. 18.* In practical tests, M-steel has, in fact, been found to give fewer distrubances in manufacture than conventional steel.

5. Publications on M-Steel

1 V. Ollilainen: *The Effect of Calcium Treatment on the Machinability of Steel,* Proc. Int. Symp. on Non-Metallic Inclusions in Steel, April 27-29 1981, Uddeholm, pp. 429 – 449

2 J. Backman: *Ca-injektion Treatment of Steels from the Users Point of View,* Scaninject III part 1, Proc. 3rd Int. Conf. on Refining of Iron and Steel by Powder Injection, Luleå, Sweden, June 15-17 1983, Mefos and Jernkontoret, 2:1 – 2:13

3 V.Ollilainen, H. Hurmola and H. Pöntinen: *Mechanical Properties and Machinability of a High-Strength, Medium-Carbon, Microalloyed Steel,* J. Materials for Energy Systems 5, March 1984, pp. 222 – 232

4 H. Pöntinen: *The Machinability of Calcium Treated Steel, Laboratory Results and Users Experiences* .The paper presented at 24. Journees Des Aciers Speciaux, Cercle d'Etudes des Metaux, May 23-24, 1985, Nantes, France 10pp

5 V. Ollilainen and H. Pöntinen:*Development of Improved Machinable M-Steel,* Proc. Int. Cong. on Utilisation of Materials Know-how in the Engineering Industry, Fed. of Finnish Metal and Engineering Industries, Sept. 10-13 1985, Espoo, Finland. pp. 37 – 53

6 C. Stanske and H.K. Tönshoff: *Zerspanbarkeitsuntersuchung von M-behandelten und handelsüblichem Vergütungsstahl,* Der Konstrukteur, 1985, 7-8

7 V. Ollilainen, I. Lahti, H. Pöntinen and E. Heiskala: *Machinability Comparison when Substituting Microalloyed Forging Steel for Quenched and Tempered Steel.* Fundamentals of Microalloying Forging Steels, Proc. Int. Symp. on Microalloying and New Processing Approaches for Bar and Forging Steels, TMS-AIME, Colorado, USA, July 8-10 1986, pp. 461 – 474

8 H. Kankaanpää, H. Pöntinen and A. S. Korhonen: *Machinability of Calcium-Treated Steels Using TiN-Coated High-Speed Steel Tools,* Mat. Sci. Tech. 3, Feb. 1987, pp. 155 – 158

9 V. Ollilainen, I. Lahti, H. Pöntinen and E. Heiskala: *The machinability Comparison when Substituting Microalloyed Forging Steel for Quenched and Tempered Steel,* Strategies for Automation of Machining, Proc. Int. Conf. of ASM, Orlando, Florida, USA, May 5-7 1987, ASM International, pp. 57 – 63

10 H. Pöntinen: *Calcium Treated Steel Shows Improved and Uniform Machinability,* ibid. pp. 65-71

11 H. Pöntinen and V. Ollilainen: *Applications of Improved Machinable M-steel in Automotive Industry,* Paper presented at 26. Journees Des Aciers Speciaux, Cercle d'Etudes des Metaux, May 19 – 21, 1987, Toulouse, France, 6pp

12 H. Pöntinen and J. Pietikäinen: *Improved Machinable Calcium Treated M-Steel,* Current Advances in Materias and Processes, (Report of the ISIJ Meeting), ISIJ, Vol.1, No.3,1988, paper 581

13 M. Paju, V. Ollilainen and H. Pöntinen: *Influence of Metallurgy on the Machinability of Low Alloy Bar Steels,* Paper presented at 27th Annual Conference of Metallurgists, CIM, August 23-31 1988, Montreal, Canada, 20pp

14 H. Nyholm: *Stål med Förbättrad Skärbarhet,* Conf. on Säkrare skärprocess för automatiserade system, Mekanförbundet and IVF, October 19 1988, Örebro, Sweden, 6pp

15 H. Pöntinen, M. Paju and P. Helistö: *Machinability of the Calcium Treated M-Steel Using Ceramic Tools and Titanium Nitride Coated HSS Tools,* 1 st Int. Conf. on The Behaviour of Materials in Machining, The Institute of Metals, November 8-10 1988, Stratford-upon-Avon, UK, 16:1 – 16:8

16 A.S. Helle and J. Pietikäinen: *Behaviour of Non-metallic Inclusions During Machining of Steel,* ibid. 22:1 – 22:7

17 A.S. Helle, M. Paju and H. Pöntinen: *Interactive Effect of Tool Material and Non-metallic Inclusions in Steel on Machinability,* "Eurotrib 89" 5th Int. Conf. on Tribology, June 12-15 1989, Helsinki, Finland, 6pp

OVAKO

Research & Quality
P.O.Box 133, S-182 12 Danderyd, Sweden

RD -93 06.90 5.000

Happy Printing AB / Sätherlund & Krook AB 1990

Disclaimer

The information in this document is for illustrative purposes only. The data and examples are only general recommendations and not a warranty or a guarantee. The suitability of a product for a specific application can be confirmed only by Ovako once given the actual conditions. The purchaser of an Ovako product has the responsibility to ascertain and control the applicability of the products before using them.

Continuous development may necessitate changes in technical data without notice. This document is only valid for Ovako material. Other material, covering the same international specifications, does not necessarily comply with the properties presented in this document.

Ovako AB
SE-111 87 Stockholm, Sweden
Phone: +46 (0)8 622 13 00