The Machinability of Engineering Materials

Edited by
Robert W. Thompson

THE MACHINABILITY OF ENGINEERING MATERIALS

Proceedings of an International Conference on

Influence of Metallurgy on the
Machinability of Engineering Materials

Rosemont, Illinois
13-15 September 1982

Sponsored by:

American Society for Metals

In cooperation with:

Iron and Steel Institute of Japan
Society of Manufacturing Engineers
Institution for Production Engineeri[illegible] Research

AMERICAN SOCIETY FOR METALS
Metals Park, Ohio 44073

Library of Congress Catalog Card Number: 82-74086
ISBN: 0-87170-160-X
SAN: 204-7586

PRINTED IN THE UNITED STATES OF AMERICA

CONFERENCE ORGANIZING COMMITTEE

Conference General Chairman

ROBERT W. THOMPSON
Inland Steel Company

* * * * * * * * * *

VIJAY A. TIPNIS
Tipnis Associates, Inc.

ROGER A. JOSEPH
Republic Steel Corporation

MOHAN D. CHAUDHARI
Columbus Metallurgical Services, Inc.

RANGA KOMANDURI
General Electric Company

JOHN C. MILLER
Reynolds Metals Company

JOHN D. CHRISTOPHER
Metcut Research Associates, Inc.

JOSEPH A. SACHA
Acme Cleveland Development Company

FRANK W. GORSLER
General Electric Company

JAY HAZRA
General Electric Company

VINOD K. SARIN
GTE Laboratories, Inc.

JOHN F. HELD
Jones and Laughlin Steel

MYRON J. SCHMENK
Cincinnati Milacron

ROBERT B. JAGERS
Valeron Corporation

CHARLES C. TOBIN
Caterpillar Tractor Company

FOREWORD

The papers in these proceedings were presented at the International Conference on the Influence of Metallurgy on the Machinability of Engineering Materials which was held on September 13-15, 1982, in Rosemont, Illinois. This conference was made possible through the effort and cooperation of the Machinability Activity of the American Society for Metals, the Iron and Steel Institute of Japan, the Society of Manufacturing Engineers, and the Institution for Production Engineering Research (CIRP).

The Machinability Activity of ASM was organized in 1974 to promote the science and technology of machinability by providing a forum for study debate on various aspects of machinability.

This conference is a continuation of a series of conferences devoted to the general theme of machinability. To date, this series consists of:

The Influence of Metallurgy on Machinability, held in Chicago, Illinois, in 1975,

The Influence of Metallurgy on Hole Making Operations, held in Boston, Massachusetts, in 1977,

Machinability Testing and Utilization of Machining Data, held in Oak Brook, Illinois, in 1978, and

Cutting Tool Materials, held in Ft. Mitchell, Kentucky, in 1980.

The proceedings of these conferences were published by American Society for Metals.

The organizing committee has endeavored to put together a wide-ranging program which is indeed relevant to those interested in machinability. Included are aluminum, brass, bronze, and nickel base alloys as well as papers on machining techniques and economics. It was the committee's intent not only to invite highly technical research papers, but also to include papers which were more practical or applied in nature.

Robert W. Thompson
Conference Chairman

CONTENTS

Effect of Additives on the Machinability of Steels

Machinability of Cast Irons

原书模糊

Machinability Testing and Techniques

EFFECT OF ADDITIVES ON THE MACHINABILITY OF STEELS

REVIEW ON THE STUDIES FOR IMPROVING MACHINABILITY OF STEEL IN JAPAN

Toru ARAKI*
Makoto OSAWA**
Shigeo YAMAMOTO*

ABSTRACT

The present review deals with the recent trends and activities of research and development in Japan, concerning free machining steels being manufactured by advanced technology and utililized in industry, improvement of needs-oriented engineering properties of freemachinable steels, and new results of mechano-metallurgical studies on improving machinability of steels.

INTRODUCTION

From former times the aimed direction of improving machining operation and machinability of work materials have been regarded as "automization, high precision and high efficiency". In recent years automation and workerless machining operation have been steadily developing and innovating in the production process in Japan, meanwhile achieving high precision of machined parts through enhanced reliability and high efficiency by high cutting speed and heavier cutting.

Such achievements are very significant for the mass-producing process by "transfer machine", for instance, as well as the multi-purpose smaller scale production by "flexible machining system". In the latter case a special kind of reliability is required for total machining system including work materials.

Steels as work materials have been developed by improving machinability itself as functions of machining efficiency for tool

* National Research Institute for Metals, Japan
** Honda R & D Ltd.

life, cutting forces, finishing roughness and precision and chip disposability. In addition the improved machinable steels are also required to be well cold-workable with enough precision and / or to have optimum microstructure without heat treatment. The present review deals with the recent features of new development of improving machinability of steels and also improvement of other useful properties of free-machinable steels in Japan.

DEVELOPMENT OF FREE MACHINING STEELS

Recent annual production of free machining steels in Japan is estimated around 900 thousand tons, of which half amount is being supplied for automobile industries as, for instance, shaft parts, gear parts etc. Representative species of these steels are resulfurized steels and leaded ones, in which the production ratio of resulfurized to leaded is regarded as 2 : 1.

Table 1 shows representative steels classified by their inclusion type in microstructure excluding stainless steel being manufactured by Japanese steel makers.

LEADED STEELS : Two Japanese steel makers are now using continuous casting method for lead steels and all makers will follow the process because of its merit in economy and also easiness in protection against hazzard of lead, and good and uniform quality of cast billet. A reported example of data from continuously (cc) leaded steel is shown in Fig.1. Lead amount of 0.06% seems to be enough to get superior chip disposability and reduced tool wear.[1]

Low-oxygen lower-lead steel [2.] has suitable properties for roller bearings and heavy duty gears which require reliability in rolling fatigue, so that the mechanical properties and performance of this kind of free machining steel can be compared to correspond non-leaded steels.

Relatively low lead amount has been proved to exert fine chip dispesability and this fact can be attributed to the embrittlement by infiltration of liquified lead particles into microcrack cleavage [3].

RESULFURIZED STEELS : In recent Japan the grades due to sulfur content are classified in two : i.e. S_1 (0.04~0.07%S) S_2 (0.08~0.12%S); S_1 is fitted for higher duty steels as trans-

Table 1. Free Machining Steels Applied by Japanese Steel Makers

	Free Cutting Additives	Applied Steels (Specified JIS)
Metallic Inclusions	Pb: [0.1~0.25%]	S40C etc., SCr, SCM, SNC, SNCM
	Pb: [0.03~0.08%], low O	SNCM, SK, low alloy steel
Sulfide Type Inclusions	S: [~0.2%, ~0.15%]; [0.3%]	SUM21, SUM32; SUM22, 23, 43
	S: (S_1) [0.04~0.07%]	S10C~S58C, SCr21, 22, SCM21, 24
	S: (S_2) [0.08~0.12%]	S10C~S58C, SUM11, 12, 31, 41, 42
	(S_1)-Zr, (S_2)-Zr	low Carbon steel, Carbon steel, low alloy steel
	(S_1)-Zr-B	S20C
	(S_1)-Te	low alloy steel, Carbon steel
Complexed Type Inclusions	S-(P,N)-Pb(Bi)-Se,Te	low Carbon steel (C≤0.15%) (nonkilled)
	S: [~0.28, ~0.3%]-Pb [0.2%]	SUM22L, 23L, 24L
Oxide Type Inclusions	Ca	S10C~S58C
	Ca-(S_1)	machine structure steel
	Ca-(S_1)-Pb [0.04, 0.2%]	S10C~S58C (SCr, SCM, SNCM etc.)
	Ti-Ca-(Si)	Carbon steels, low alloy steel

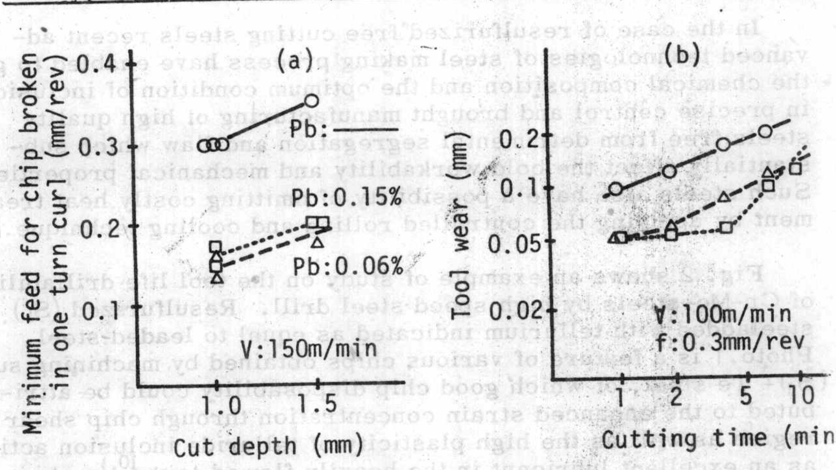


Fig.1(a)(b). Machinability of Continuously Cast Leaded Stee
(Tool:P10[-6,-6,6,6,15,15,0.4])

mission parts of automobile and for the usage of cold forgings, whereas S_2 has better machinability but some shortage of mechanical properties, which are dependent on the shape of sulfi de inclusions and can be improved by shape-control in manufacture.

Shape control of sulfide inclusions has been studied and practised by utilizing addition of tellurium[4,5.], zirconium[6)7.], rare earth elements[7.], titanium[8.] and calcium[9.] in relation with oxygen content of molten steel.

Telluride together with sulfide has a trend to make complex inclusions and to make sulfide take ellipsoidal shape[5)] instead of stringer type. A few telluride can make entectic with sulfide, and at high temperature liquified entectic around plastic sulfide may react as lubricant during hot rolling process of steel, which mechanism results in ellipsoidal shape of sulfide inclusions .

Zirconium has another effect on sulfide : the resulted MnS-Zr_3S_4 eutectics have low plasticity and will give an ellipsoidal shape[6.]. The favorable effects by titanium, rare earth and calcium are thought to be resulted from similar mechanism, in which cases oxygen contents play a role to get the optimum distributions in shape and amount.

In the case of resulfurized free cutting steels recent advanced technologies of steel making process have enabled to get the chemical composition and the optimum condition of inclusions in precise control and brought manufacturing of high quality steels free from detrimental segregation and flaw which substantially affect the cold workability and mechanical properties. Such steels also have a possibility of omitting costly heat treatment by applying the controlled rolling and cooling technique.

Fig. 2 shows an example of study on the tool life drillability of Cr-Mo-steels by high speed steel drill. Resulfurized (S_1) steel added with tellurium indicated as equal to leaded steel. Photo.1 is a feature of various chips obtained by machining such (S_1)+ Te steel, of which good chip disposability could be attributed to the enhanced strain concentration through chip shear region as well as the high plasticity of telluride inclusion acting as an excellent lubricant in the heavily flowed layer[10.] in chip.

Fig. 3 shows data of flank wear of carbide tool machining 0.45% carbon steels (S45C) with warious inclusions, lead,

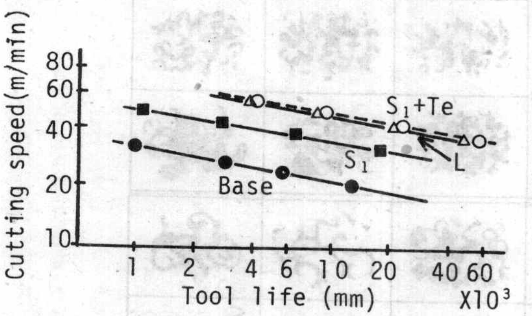


Fig.2. Drill Life Curves for Normalized Free Cutting Steels (Drill:5mm$^{\phi}$)

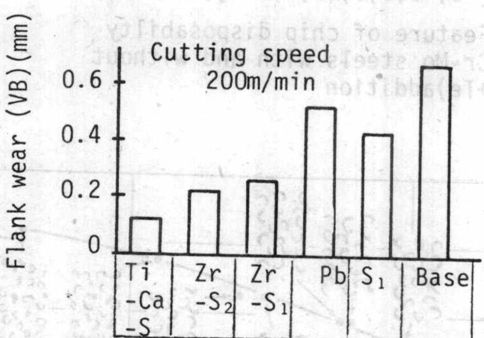


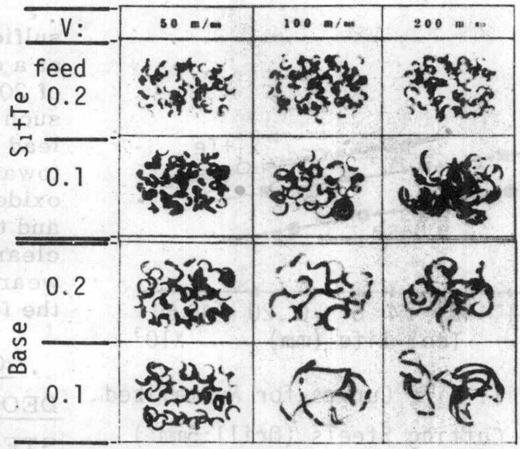
Fig.3. Flank Tool Wear of Carbide Tip (Normalized medium carbon steels)

sulfides and oxides at a cutting speed of 200 m/min. At such high speed, lead tends to affect toward inferior and oxides of calcium and titanium to clearly improve tool wear as stated in the following.

CONTROLLED DEOXIDIZED STEEL :

Calcium deoxidized steel has a kind of free machining properties as firstly discovered by Opitz et al[11.]. Calcium silicate inclusions in steel have in fact a wear protecting effect forming thin oxide layer (Belag) on the rake face of carbide tool when machining relatively high cutting speed such as 200 m/min. Titanium oxides combined with manganese oxide in steel was discovered to have a similar effect and especially favorable for protecting flank wear of carbide tool containing titanium carbide.[12, 8.]

In such controlled deoxidized steels the special types of oxide inclusions are playing a role of free-machining additives at high cutting speed conditions with special carbide tools, and so the controlling condition of deoxidation of mother steel is somewhat sensitive. But recent advanced techniques in steel making process are enough to be able to manufacture the free machinable steel in practical use as described in Table 1.



(Tool:P10[-5,-5,5,5,30,0,0.4],D:2.0mm)

Photo.1. Feature of chip disposabilty of Cr-Mo steels with and without (S_1+Te)addition

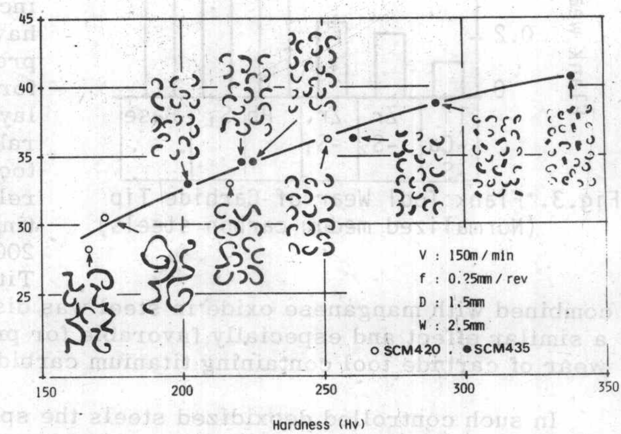


Photo. 2 The appearance of chips of steels mixed with martensite

STATUS OF FREE CUTTING STEELS UTILIZED IN AUTOMOBILE INDUSTRY

In the automobile industry in Japan, free machining steels resulfurized (S_1) and leaded (0.1~0.3%), were adopted by JAMA (Japan Automobile Manufacturers Asso.) - Specifications in 1971, and have been continually contributing to the improvement of productivity and rationalization to a large extent.

From the viewpoint of the minimum cost for parts, leaded free cutting steels, resulfurized free cutting steels, calcium free cutting steels as well as complex type ones including low leaded type (Pb 0.05~0.10%) have been investigated and put to practical use with fine performance and high yield in production.

According to recent statistics, more than 300 thousand tons annual use of free cutting steel are reported as for the automobile parts. In 1957, when leaded steels were adopted for use to automobiles, the amount was only 500 tons per year and is now 600 times as large. From now, the matching among advanced cutting tool materials, machine tools, labor saving by introducing robots and cutting work materials is the key problem for the stabilization of product quality and cost saving.

Of course there are problems of saving resourses and energy, for instance concerning cobalt, tungsten and tantalum which are major elements for cutting tools and conservation of energy for cutting power.

The next Table 2 shows the typical free cutting steels and their applications in Japanese automobile industry.

IMPROVEMENTS BY MEANS OF MICROSTRUCTURE OF STEELS

<u>NON-HEAT-TREATED HIGH STRENGTH STEELS</u> : High strength steels to be used for shaft parts of automobiles are usually heat treated and have tempered martensitic structure, and the final cost depends fairly on the heat treatment.

Application of controlled rolling and cooling techniques have enabled to omit the heat treatment by adding minor elements such as vanadium, niobium and titanium to steel, and to obtain the comparable high strength level of 800~900 N/mm^2 by grain refinement and precipitation. This is also possible in the case of hot forging process.[13][14]