Bar Automotive Group Machinability Summit

June 26, 2012

Southfield, MI

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Executive Summary

The Steel Market Development Institute (SMDI) held a Machinability Industry Summit Meeting on June 26, 2012 with the purpose of defining a strategic roadmap for the Machinability Sub-committee of the SMDI Bar Applications Group (BAG). The BAG Machinability Sub-Committee is comprised of representatives from the automotive OEMs, steel industry and academia and has been meeting since 1991 with the original goal of developing bar steel machinability data for the automotive industry. The goal of the sub-committee is to provide machinability data to all markets that use or could potential use steel long products.

Among other accomplishments, the BAG Machinability Sub-committee has developed a Bar Machinability Database, which is comprised of test data from a single point turning test, and a machinability calculator that can estimate cutting tool life based on defined criterion (The **Bar Steel Machinability Estimator** can be accessed on the www.autosteel.org webpage.) However, there is little apparent industry knowledge of these accomplishments, which necessitated the need to determine if future work along these lines was of value to the industry. Furthermore, over the past twenty years, there have been significant advancements in steel, heat treatment, tool coatings, cutting tools and equipment, which may have changed the industry machinability data needs. The purpose of this Machinability Summit Meeting was to determine what steel machinability data, in terms of materials and operations, was of interest to the industry and how the Sub-Committee might develop pre-competitive data that would enable increased use of steel.

The Summit Meeting extended invitations to and had attendance from the automotive OEM and supplier, steel cold finish, general machined products, academia, cutting tool, equipment and machine tool suppliers to obtain more comprehensive input from the machining industry. The meeting began with five presentations to provide attendees with background information on AISI, SMDI, BAG and the BAG Machinability Sub-Committee, as well as technical work currently being pursued by the Sub-Committee. The presentations can be accessed through the Bar Machinability link on the www.autosteel.org webpage.

The presentations were followed by the Roundtable discussion, with an open forum revolving around five main topics as listed below.

> **Steel:** There is a need to better understand how variations in steel chemistry, alloy additions, microstructure, and surface-to-core uniformity affect machinability. The main theme in this topic was consistency, where steel variation is attributed to excessive machine downtime, reduced productivity and therefore increased cost.
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> **Cutting Tools:** There is an interest in evaluating the effect of different cemented carbide surface treatments and coatings on machining. The lack of a consensed test methodology

and the need to focus on pre-competitive data are initial obstacles that have to be addressed before pursuing this topic.

Machining Operations: There is interest in developing machining data for operations other than turning, such as drilling. There is an assumed belief that single-point turning test can be used as a rough predictor of performance in other machining operations, which discourages this avenue of investigation. However, turning is not typically the rate limiting machining operation and the lack of correlation between turning and other machining operations suggests that this path of investigation is of interest to the industry.

Testing: As mentioned in the previous topic, the development of data for machining operations other than long turning is an area of interest but there are limited published test results from other test methodologies (milling, face turning, plunge turning and screw machine turning) to effectively compare steel machinability for machining operations other than long turning. The popularity of the single point long turning test encourages continued development of turning data if the industry found this information of value. As will be discussed in this report, there was general agreement in expanding the machinability database to include turning data for European steels, carburizing grades, micro-alloy grades, stainless steels, hardened steels and for different microstructures (annealed, normalized, quench and tempered) of the same grade.

Modeling: Although mentioned, there was no significant discussion applied to modeling, which is likely reflective of meeting's composition and lack of participants from academia.

The dominant theme among all the topics was the need for consistency and predictability. Machine downtime is the largest contributor to the costs of machining where changes in steel sourcing, lot-to-lot variation, surface-to-core microstructural variation, etc. may have an adverse impact on cutting tool life. There is a shared need among the participants to better understand the factors that affect machinability to improve machining consistency, minimize downtime, and better predict machining throughput and cost.

The results from the Machinability Industry Summit Meeting are expected to be used by the Machinability Sub-Committee for program planning. It is also expected that this meeting will encourage the development of new industry/government/academia collaborations to address tasks of mutual interest with the goal of accelerating the use of steel as the material of choice for automotive and industrial applications.

Acronyms

AISI	American Iron and Steel Institute
A/SP	Auto/Steel Partnership
BAG	Bar Applications Group
CAE	Computer Aided Engineering
DOE	Department of Energy
FOA	Funding Opportunity Announcement
ICME	Integrated Computational Materials Engineering
OEM	Original Equipment Manufacturers (vehicle producers)
R&D	Research & Development
SMDI	Steel Market Development Institute
USCAR	United States Council on Automotive Research

Introduction

There have been many advancements in the machining industry, such as improved cemented carbides, coatings and multi-axis machines capable of producing fully machined complex geometry components from CAD data. Likewise the steel industry continually improves with the development of new steel alloy grades, heat treatments, etc. These changes coupled with the need for higher strength steel to improve system performance and reduce weight have driven the need for more fundamental understanding of the factors that contribute to the machinability of steel.

The goal of the Steel Market Development Institute (SMDI) Bar Applications Group (BAG) is to provide the metalworking industry with information on which to build their processes in manufacturing components from steel long products (bars and tubes). The Machinability Sub-Committee is one of the sub-committees under BAG that has 1) developed a single-point long turning test for evaluating the machinability of steel, 2) compiled comparative machinability data on a number of steel alloys, and 3) developed a steel machinability calculator to estimate cutting tool life based on defined criterion. Despite the perceived value of this work there is little evidence that industry is aware of the machinability calculator and database giving rise to concerns over the value of the work, whether to test additional materials for input into the database and whether the Sub-Committee should continue to meet.

The Machinability Sub-Committee is composed of representatives from automotive OEMs, academia and the steel industry. The Sub-Committee develops information needed by the machining industry for material selection, process development and for improving understanding of the factors that influence the machinability of steel. In preparation for the Summit Meeting, the Sub-Committee invited representatives from the non-automotive OEMs, general machining industry, machining cutting tool/equipment suppliers and machining suppliers to gain a more diverse but industry representative input on the issues that are important to the machining industry.

The Machinability Summit Meeting was held on June 26, 2012, at the SMDI offices in Southfield, Michigan. The goal of the Summit was to determine the following:

1) The value of work done to date
2) Whether there was justification to conduct future work
3) What work should be done by the Machinability Sub-Committee?
4) If there was interest by participants in joining the Machinability Sub-committee

The meeting was organized into three sessions, the first being an introduction into AISI, SMDI, BAG and the BAG Machinability Sub-committee, the second being a recap of technical work being pursued by the sub-committee and the third being a Roundtable discussion. The focus of this report is to summarize the Roundtable discussion sufficient for the Machinability Sub-

committee to develop future plans.

Presentations

The Machinability Summit Meeting began with two introductory presentations.

1. Introduction to AISI/SMDI – Dave Anderson
2. SMDI Bar Machinability Database – Joe Tarajos

The introductory presentations were followed by three technical presentations that gave an overview of technical work performed and in current development by the Machinability Sub-Committee.

1. Machinability Testing of Steel – Michael Finn
2. Cutting Tool Trends and Technology – Curt Holbrook
3. Single Point Turning Tests using Coated Carbide Cutting Tools – Mike Burnett

Roundtable Discussion

A survey was submitted to the meeting invitees as a prelude to the Roundtable Discussion. The questions from this survey were used as a guide for directing discussion and will as serve an outline for this report.

Is machinability still an issue?

The unanimous response was, “Yes, machinability is still an issue”.

How would you define machinability?

The answer to this question was diverse and reflected the differences in invitee roles, automotive OEM, cutting tool supplier, machining supplier, etc.

1. Machinability is a property of a material, usually a metal, characterizing its ability to be machined, cut or ground by removing material to shape an engineered component.
2. Machinability is the ease of machining while maintaining required tolerances and acceptable cutting tool life.
3. Machinability is a combination of cutting tool wear and chip control.
4. Machinability is the ability to cost-effectively remove metal to create a component that meets all functional requirements.

The first definition defines machinability as a material property. The second and third definitions define machinability from a manufacturing perspective, where cutting tool life is primary concern. The last definition reflects an OEM perspective, which views machining a means to produce components to specified requirements. No further effort was made during the Roundtable Discussion to define machinability but these definitions served as boundary conditions for further discussion.

Are you aware that SMDI machinability data exists?

The survey responses indicated that outside of the BAG Machinability core group that there was no awareness of the SMDI machinability database or the machinability calculator. SMDI is currently discussing the merging of the machinability data with the fatigue data, which was generated by SMDI Steel Fatigue Sub-Committee. The group recommended that the database and calculator be made available through the SMDI website and promoted whenever possible such as through ASM International and/or associated companies and organizations.

Where do you see machining going into the future?

The industry appears to be moving in the direction of lightly attended machines and for comprehensive machining jobs where the component is completely machined coming off the machine. This emphasizes the need for improved chip control, durables cutting tools, and consistent steel microstructures to reduce machine downtime.

The group briefly discussed the impact of environmental regulation but this was not seen as a significant issue for the machining industry that has already taken steps to classify the toxic content of the materials being machined and recycled. Still, there is an expectation that free-machining leaded steels will continue to decline.

From a machining supplier perspective, the ability to service, operate and program machines typically requires diverse skill sets. The industry recognizes that there is lack of skilled operators, especially those that can cover all three skill sets. Other than to promote the machining industry through trade schools and universities, training and education is not an area that falls under the scope of the BAG Machinability Sub-Committee.

What are your major issues in the machining of steels?

The answers to this question are summarized in Table 1 and reflect survey responses as well as issues extracted from the Roundtable Discussion. Like the definition of machinability, the answers to this question were quite diverse and reflective of the responder's background.

Table 1: What are your major issues in the machining of steels?

How do I estimate power requirements?	Broaching
How can I estimate cutting tool life?	Chip Control
Reducing cost of machining with longer cutting tool life, down time and reworks/rejects.	Heat
Machinability consistency and improving quality of machined part	Dimensional Control
Material (Hardenability, grain sizes, microstructures)	Slow Cycle Times
What is the best cutting tool material?	Productivity
Variable surface chemistry from lot to lot	Tearing
Reduce downtime is biggest concern in cost perspective	Surface structure, integrity, and finish
Machining parameters change/vary from the first job to the 1000^{th} job through the machine	How sulfur changes consistency

The Roundtable Discussion categorized this general list into two specific issues, "Consistency" and "Predictability."

Consistency

The single biggest cost driver in machinability is unplanned machine downtime, which is mostly reflective of steel variation (i.e. lot-to-lot, steel grade variation between suppliers, surface to core, etc.). The factors that contribute to day-to-day variation are neither always identified nor understood and include variation induced by the work-piece material, cutting tools and equipment. The primary emphasis of this issue is on the steel being machined but there is a cutting tool component, which was mentioned but not discussed in detail.

Predictability

The ability to estimate costs, component throughput and scrap rates is dependent upon being able to predict the ability of material to be machined to the required dimensions and surface finish. Like "Consistency", this issue has both steel material and cutting tool components where steel and cutting tool selection to achieve optimum throughput are dependent upon understanding the machinability of the steel and durability of the cutting tools being used to machine the steel.

What are the areas of most interest?

Table 2 provides a list of survey responses to this question.

Table 2: What are the areas of most interest?

Turning	
Milling	Pocket Milling
Drilling	Hole-making Reaming Burrless holes
Broaching	

The discussion on machining operations garnered the most input during the Summit meeting. Representatives from the BAG Machinability core group restricted the scope of this topic stating that the group only develops precompetitive data, which does not permit the comparison of steel suppliers or cutting tool between suppliers.

From this discussion emerged several recommendations for future work, which fall under two headings.

1. Expansion of the turning database
2. Development of a drilling database

Expansion of the turning database

The prior development of the single point turning test and turning data database provided significant support to the group's desire to expand the database along the four topics listed below.

A. Effect of steel processing and chemistry on machinability

A number of initiatives fell under this topic.

1) Several participants echoed the need for data that shows the difference between hot-rolled, cold-drawn and annealed steel bars.
2) As environmental regulations tighten, there is an expectation that leaded steels will diminish so alternative free-machining grades is desired.
3) Evaluation of elemental contributions to improve machinability, i.e. sulfur, bismuth, lead, carbide shape control, etc.
4) Most machinability data is based on the analysis of the steel bar core. The surface of the bar can differ in terms of chemistry, inclusions, and microstructure which can significantly affect steel machinability. Better understanding of the differences between the surface and the core is encouraged to better characterize the machinability data.
5) Evaluate chip control as a means of characterizing steels.

B. Effects of heat treatment on machinability

The need for improved dimensional control and surface finish coupled with advances in cutting tool material and coating durability have driven a move toward machining hardened steels. There is a need for machinability data for steel grades in the quench and tempered condition in addition to annealed and/or normalized condition. This suggests testing of the same grades of steel in different heat treat conditions.

C. Development of upper and lower machinability limits

The trend has been to provide nominal machinability data but there is a desire for lower and upper bands to be able to capture expected material variation, i.e. supplier, grade and microstructure.

D. Expansion of database to cover European grades, micro-alloy steels and stainless steels.

There is a need for machinability data for different types of steel. The single point turning test provides a means to compare the relative machinability not only of different steel grades but different steel types, i.e. the difference in machinability between stainless

steel and free machining steels. The list of suggested steels is provided in Table 3.

Development of a drilling database

There was general agreement that drilling data would be useful but the lack of an agreed upon test was a significant detriment. There was general agreement that what holds true for turning holds for drilling. However, drilling is a rate limiting operation with respect to cycle time and therefore important in terms of through-put and cost. Should a test be developed, it may turn out that what is good for drilling is good for turning where drilling is a better predictor of machinability due to its perceived increased sensitivity to machining parameters and conditions.

What grades of steel do you feel should be evaluated

Table 3 provides a list of steels that the group suggested should be tested based on survey responses as well as the Roundtable Discussion.

Table 3: What grades of steel do you feel should be evaluated

All major material grades utilized by the automotive industry
Newer steels used in the auto and oil/gas industries
Low carbon steels
Carburizing/nitriding grades
Micro-alloyed and inclusion engineered steel
Stainless steel
European Grades*
Alloy Steels • 4140 • 4340 • 8620 • 52100
Stainless steel • Duplex stainless steel • PH stainless steel.
Tool steels • H13 • M2 • M42

*Although the SMDI BAG Machinability core team is composed of U.S. steel suppliers, these mills provide European grades of steel so it would be possible to test and provide machinability data on these steels.

Are there recommended standardized tests for evaluation?

No additional machining tests were provided for discussion.

Where should SMDI BAG Machinability Group go from here?

This question is directed toward exploration of machinability topics not previously discussed. A number of survey questions fell under this general question and include discussion on whether the BAG Machinability Group should evaluate the following.

Chip Control	High Pressure Coolant	Dry Machining
Cold Drawn Reduction Ratios	Competing Processes	Surface Finish

Although interest was expressed in each of these categories, the limited amount of open discussion on these topics suggested that they were of secondary concern to the primary issues of "Consistency" and "Predictability".

Modeling

The subject of modeling machinability was briefly discussed, which would fall under the issue of "Predictability". Computer modeling and simulation is strongly encouraged by the DOE as evidence by the last couple DOE Funding Opportunity Announcements (FOA). The Sub-Committee was encouraged to look at modeling as it may be a source of funding and facilitates the ability to predict steel machinability. A possible project would be "Predictability of steel response to cutting/turning."

SMDI BAG Machinability Sub-Committee Membership

There was insufficient time to fully explore whether there should be changes to the composition of the BAG Machinability Sub-Committee. The core team is comprised of automotive OEMs and steel company members but the Sub-Committee often invites academia, machining companies, equipment manufacturers, consultants, etc. to participate and advise the Sub-Committee. The invitee list (APPENDIX III) for the Machinability Summit meeting reflects the thought that it may be beneficial to expand the Sub-Committee membership to address future machinability needs.

Summary

The group was openly supportive of those initiatives that improved the ability to more accurately predict machinability (Predictability) and identified the factors that led to variation in machinability (Consistency). The core group tempered these responses by limiting initiatives to those that generated data and not "problem solving" initiatives. The consortia nature of the BAG Machinability team necessitates precompetitive work, where generalized information gathering is permitted but directed comparisons, for example steel grades between supplier, is not permitted.

Predictability is driven by the need to accurately predict the cost of machining as a function of material machinability, cutting tool life, through-put, etc. Initiatives along these lines improve the competitiveness of the machining industry and are primarily data driven. Initiatives that fall under "Predictability" and within the BAG Machinability mission include modeling, developing machinability tests that correlate with actual machining process results, and populating material databases that facilitate optimum steel selection.

Consistency is driven by the need to minimize unplanned downtime, which is the largest contributor to machining cost. Supported pre-competitive initiatives along this line are those that identify the steelmaking, chemistry, steel processing/treating and microstructural factors that affect machinability.

Under the "Consistency" and "Predictability" themes, two focal areas emerged during discussion, which were 1) The expansion of the turning database and 2) The development of a drilling database. Drilling is hampered by the lack of an industry standard test, which tends to discourage evaluation. However, its impact on cycle time, productivity and cost encourages consideration. The industry acceptance of the single point turning test provides an incentive to continue steel turning testing and expansion of the turning database. This was further supported by the desire to expand the database to include other types of steels as well as the effect of heat treatment on steel machinability. The dominant turning initiatives are listed below but each initiative includes a number of sub-initiatives discussed in the body of the report.

1) Effect of steel processing and chemistry on machinability
2) Effects of heat treatment on machinability
3) Development of upper and lower machinability limits
4) Expansion of database to cover European grades, micro-alloy steels and stainless steels.

The value of work accomplished as well as future work is dependent upon the ability to transfer this knowledge to the industry. The group strongly encouraged an outreach initiative to make the database and machinability calculator more known and accessible.

APPENDIX I – MACHINABILITY SUMMIT ROUNDTABLE AGENDA

Steel Market Development Institute

A business unit of AISI
www.smdisteel.org

MEETING AGENDA

Meeting Name: Machinability Summit Roundtable

Meeting Time: June 26, 2012 @ 10:00 am

Meeting Location: AISI Southfield Office

10:00	1.0	**INTRODUCTION**	**Anderson**
		1.1 Attendance	
		1.2 Antitrust Guidelines	
		1.3 Emergency Procedures	
		1.4 Agenda Review	
10:10	2.0	**INTRODUCTION TO** Long Products Market Development Group **(LPMDG)**	
		2.1 Mission	**Anderson**
		2.2 Projects	
		i) Fatigue	
		ii) Machinability	
10:20	4.0	**MACHINABILITY SUBCOMMITTEE**	
		4.1 Early History	**Tarajos**
		4.2 Current Activities	**Burnett**
		4.3 Defining Machinability	**Finn**
		4.4 Cutting Tool Industry Perspective	**Holbrook**
11:00	3.0	**PURPOSE OF THE INDUSTRY SUMMIT**	**Tarajos**
		3.1 BAG goals	
		3.2 Comments from attendees	
11:05	5.0	**INDUSTRY INPUT–ROUNDTABLE DISCUSSION**	**McCarty**
12:00	6.0	**WORKING LUNCH**	
12:30	7.0	**CONTINUATION OF INDUSTRY INPUT–ROUNDTABLE DISCUSSION**	**McCarty**
2:00	8.0	**ADJOURNMENT**	

APPENDIX II – JUNE 26, 2012 SMDI MACHINABILITY SUMMIT NOTES

Meeting Notes from Jeff McCague

- Consistency of machinability is a big issue, emphasis on a manufacturing perspective and day to day machining consistency.
- On major issues in machining of steels:
  - Variable surface chemistry from lot to lot
  - How sulfur changes consistency, brought up modeling proposal
  - Reduce downtime is biggest concern in cost perspective
  - Machining parameters change/vary from the first job to the 1000^{th} job through the machine
- In future trends, Job comes off the machine complete, and lightly attended.
- Turning data expanded, more grades added to database, expanding to European standard grades. Coming from Miles Free response in survey; '4130 is an oft used overlooked material. 1018 is a problematic grade. 1215 would be of interest to a large segment of the market who feels that the loss of 12L14 is likely or inevitable.'
- Effects of heat treatments, cold vs. hot
- Range of band in machining curve; have data on high and low restraints
- Big emphasis on drilling data
- The overall group seemed interested; Miles was pushing for the smaller companies while Timken has a bigger audience already. Cummins seemed only interested in drilling data, as were a few others.

Meeting Notes from Joe Tarajos

How would you define Machinability?

- Key to all machinability is consistency and predictability.
- Cost effectiveness—how many parts can you invoice-parts per unit time produced is key.
- Consistency is the biggest problem for manufacturer. Buyers buy from difference sources.
- Day to day process variations and cannot determine what has changed.
- Consistency spans material properties and manufacturing

- Surface chemistry can affect consistency of machining properties and that affects the process. Analysis is done on core not the surface. Instead of concentration on cutting tools maybe we should look at surface affects.
- Predictability may be more directed to a modeling project. May want to look at a program via DOE for modeling the predictability of cutting responses to steels.

What are the major issues in the machining of steels?

- Scrap has to inventoried by toxic content. We have to deal with it—
- What is the biggest cost contributor to machining?
    - Downtime
    - Inconsistencies in process
- Leaded steels being eliminated, should we look at replacements with other non-toxic constituents?
- Leaded steels are not advantageous with carbide cutting tools (high speed machining).

SMDI Database

- Apparently people don't know that the calculator is on the website.
    - Make it easier to find
    - Other organizations to put link from their websites to the calculator.
    - Add to the steel section of the ASM Handbook.

Future Trends

- Lightly attended manufacturing instead of lights out manufacturing. This requires chip forms and consistent cutting tool life that facilitate lightly attended manufacturing.
- Finish the part on the machine—no additional operations. The raw part goes in and comes out completely finished in the same machine.
- Less machinists
- Dry machining vs. high pressure coolant machining
- Hard turning—is this important? Yes. Is machinability of hard turned steels of interest?
- Machine tool trends gong to smaller machines because parts are getting smaller.

What areas are of the most interest?

- Turning:
    - Hard turning
    - Heat treat variables effecting turning
    - Grades should be tested in different, common heat treat conditions. Machinability variations taking into account heat treatment.
    - Cold drawn vs. annealed
    - Take another look at grades already tested and test in various heat treat conditions

    - Back fill and add more steel grades to the test matrix
    - Look at carburizing grades coming over from Europe and made by US mills.
    - Look at chip control and use it to further characterize the steels
- Drilling:
    - Drilling is the pace setter for the process. It is the cycle time determinant.
    - No current standardized test for drilling exists.
- Milling and Broaching:
    - No comments were made by group relative to these processes.

Conclusions:

- Use existing turning methodology;
    - Evaluate effect on machinability of various common heat treatments on grades test grades
    - Look at effect of cold drawing on machinability
    - Evaluation of the effect on machinability using various elements that enhance machining.
    - Increase grades tested and expand to European grades made in US mills.
- Make machinability calculator more accessible. Get the word out that it is available and how to use it.
- Drilling is important. Longer term development. Interest in HSS vs. carbide drills, does it follows the turning trend? If it does, by how much?

APPENDIX III – ATTENDEES

Joe	Tarajos	AISI
Richard	Howell	Chrysler
Michael	Shaw	Chrysler LLC
James	Bitner	Cummins
Marian	Trocki	Cummins
Mike	Finn	Finn Metalworking and cutting solutions
Jody	Burke	Gerdau
Eric	McCarty	Materials Technologies Consulting
George	Steele	Mosey Manufacturing
Doug	Clauson	Niagara LaSalle
Miles	Free	PMPA
Curt	Holbrook	Sandvik
Don	Graham	Seco Tools
David	Anderson	SMDI
Jeff	McCague	SMDI
Bennie	Howard	SMDI
Mike	Burnett	Timken
Pete	Jarocewicz	Timken
Jim	Flanagan	Timken
Vikram	Bedekar	Timken