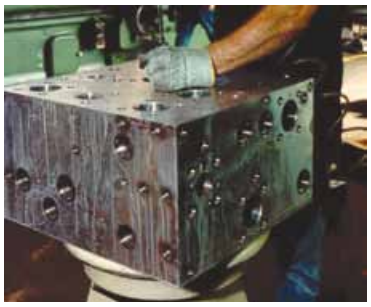
ArcelorMittal USA

Plate

Free-Machining Steels: Controlled sulfur additions to enhance machinability and extend tool life

Introduction

ArcelorMittal USA is the only steel producer providing three families of steels to meet the complete free-machining requirements of the metalworking industry, C1119™/C1144™, Clean-Cut® Carbon and Clean-Cut® Alloy steels contain controlled sulfur additions to provide enhanced machinability.



Increased sulfur levels in these steels result in higher levels of manganese sulfide inclusions. These inclusions reduce machining loads and tool wear, as well as provide better chip disposability and breakage characteristics when compared to lower sulfur steels. The effect of sulfur on machinability is illustrated in Figure 1. The lubricating effect of sulfides and their contribution to chip breakage is shown in Figure 2. Thus, tool life is extended and machining time is usually decreased. Surface finish and dimensional stability may also be improved. For many applications, the advantages of ArcelorMittal USA's free-machining plate steels can translate into significant dollar savings for the end user. The chemical compositions of ArcelorMittal USA's free-machining steels are summarized in Table 1.

Figure 1
Schematic Effect of Sulfur on Machinability

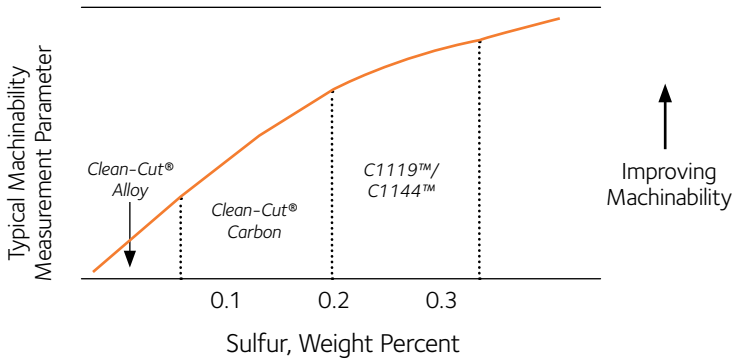


Figure 2
Schematic of Machining Process Interacting with Sulfides

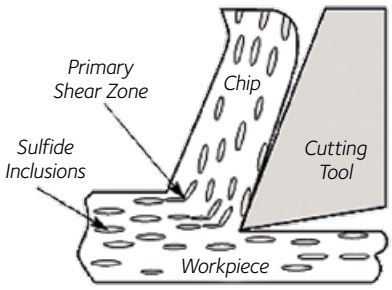


Table 1
ArcelorMittal USA's Free-Machining Steels

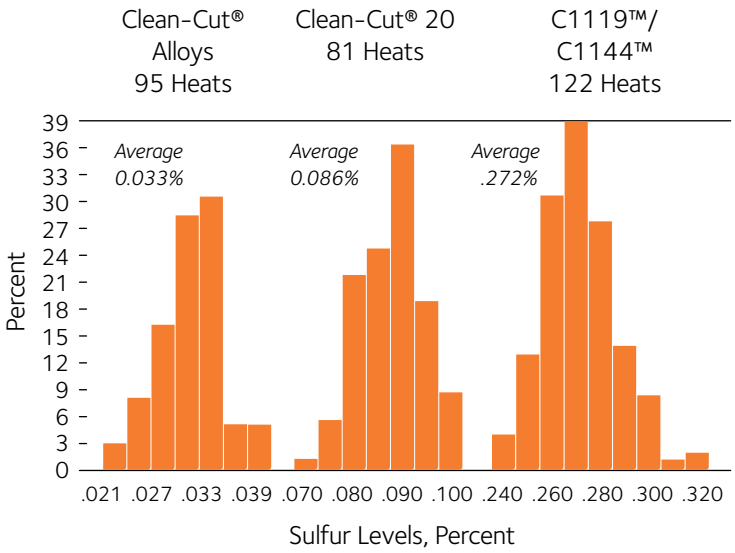
	Chemistry*				
	C	Mn	P	S	Si
C1119™/C1144™					
C1119™	.17/.23	1.00/1.30	.04 max.	.20/.33	.30 max.
C1144™	.40/.50	1.00/1.30	.04 max.	.20/.33	.30 max.
Clean-Cut® Carbon Steels					
Clean-Cut® 20**	.14/.22	1.20/1.50	.04 max.	.06/.12	.10/.40
Clean-Cut® 45**	.42/.50	1.20/1.50	.04 max.	.06/.12	.10/.40
Clean-Cut® Alloy Steels	Available chemistries with sulfur of .02/.04%* AISI 4140, 4142, 4150, 8620, MTD® #1, #2 and #4*				

* weight percent by heat analysis

** Clean-Cut® steels are also calcium treated

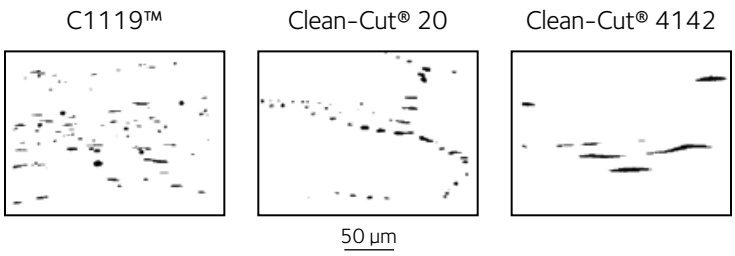
The sulfur content of a steel is critical to performance during machining. The reproducibility of the sulfur contents in ArcelorMittal USA's Coatesville, PA melted, free-machining steels is demonstrated in Figure 3.

Figure 3
Distribution of Sulfur LevelsThree Families of Free-Machining Steels



Because of the different sulfur levels in C1119™/C1144™, Clean-Cut® Carbon and Clean-Cut® Alloy steels, the sulfide inclusions structure and, thus, the machining characteristics are also different. Comparisons of the sulfide inclusion structures are show in Figure 4.

Figure 4



C1119™/C1144™ Carbon Steels

These grades have been available for over 30 years and are very widely used free machining plate steels. They are available up to 8" thick and have specific individual capabilities as noted below:

C1119™ is an ideal grade for many applications requiring extensive machining and a smooth surface finish. It may also be flame hardened to locally improve surface properties. Improved machining characteristics reduce machining costs and residual stresses while improving surface finish in comparison to ordinary grades. Typical applications include machinery bases, plastic and rubber molds, threaded parts and die holders.

C1144™ offers higher strength and hardness and is applicable where resistance to deformation and wear are essential. It may be flame hardened to further enhance surface properties and frequently is used as an economical replacement for more expensive quenched and tempered alloy grades. Typical applications include gears, sprockets, molds, dies, cams and machine ways.

Clean-Cut® Carbon Steels

Developed in 1978, Clean-Cut® carbon steels provide free-machining characteristics and are available in two carbon levels as Clean-Cut® 20 and Clean-Cut® 45. Additionally, Clean-Cut® steels are calcium treated to reduce the influence of oxide inclusions on tool wear. These steels are available in thicknesses up to 15 in. and can be inspected for internal soundness to ASTM A435 requirements when so specified. Used primarily in thicknesses greater than 6 in., these steels are used widely in manifold blocks and surface-critical mold applications

Clean-Cut® Alloy Steels

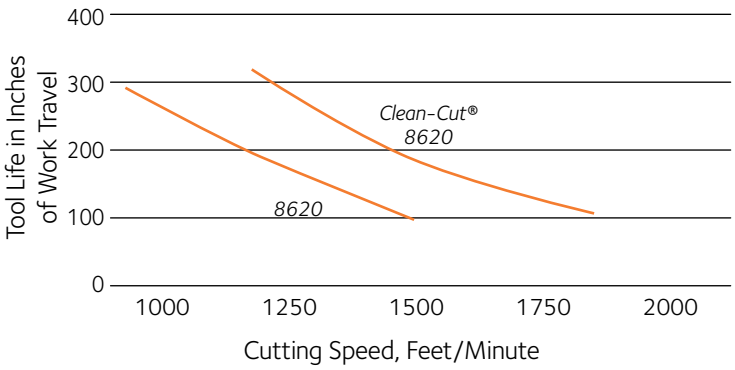
Clean-Cut® alloy steels are offered in AISI grades 4140, 4142, 4150, 8620 and in the ArcelorMittal USA prehardened steels, MTD® #1, #2 and #4. These steels are produced with a sulfur content of .02% to .04% and exhibit improved machinability over the lower sulfur steels, particularly in milling and drilling. This improvement is also assisted by the calcium treatment given to these steels. Milling test comparisons are shown in Figure 5.

Other Steels

Contact ArcelorMittal USA Plate offices for other controlled sulfur addition carbon or alloy steels that may be of interest.

Face milling of Clean-Cut® 20
Note consistent chip configuration

Figure 5
Face Milling



Work Material:	8620 steel, 149 HB	
Face Mill	4" diameter, single tooth	
Insert	Kennametal Grade KC850 SNG-432	
Geometry	Axial rake: -5°	End cutting edge angle: 45°
	Radial rake: -5°	Relief angle: 5°
	Corner angle: 45°	Nose radius: 0.030 in.
Feed	0.010 ipt	
Depth of Cup	0.10 in.	
Width of Cup	2.0 in.	
Setup	Climb milling	
Cutting Fluid	Dry	
Tool life end point	0.015 in. uniform wear 0.030 in. localized wear	

Processing ArcelorMittal USA Free Machining Steels

Machining

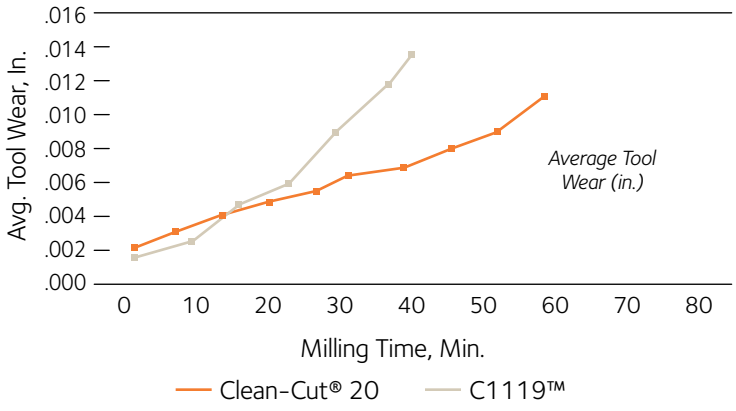
Quantifying the improvements in machinability through sulfur additions is a very complex endeavor. Not only are there numerous machining methods, but the subjective interpretation by machinists on the shop floor in using the steels can be most important in steel selection. Choice of machining variables (feeds, speeds, lubrication and tooling) can have a great influence on productivity and surface finish.

Hardness of the steel can also affect machinability. Hardness varies by thickness and heat treatment within each grade. Generally, carbon steels with 0.20% nominal carbon are 120-170 HB, while the 0.45% carbon steels are 170-230 HB. The hardness of the alloy steels can vary significantly based on chemistry, thickness and heat treatment. The sulfur levels of all three families of steels assist machinability through promoting good chip formation. A comparison of Clean-Cut® 20 to C1119™ is shown in Figure 6.

Drilling one of many holes in a Clean-Cut® 20 plastic molding machine manifold block.

Surface grinding of a manifold block.

Figure 6
Average Tool Wear as a Function of Milling Time



Machined Surfaces

Due to the intentional presence of sulfide inclusions in these steels, there may be indications on highly polished surfaces. Modifications of cutting parameters can often minimize this condition. Inspection of finished surfaces, using high-resolution techniques such as dye penetrant or magnetic particle, will outline areas of inclusions. Careful interpretation of results is required. Because of sulfur level differences, Clean-Cut ® carbon steels will have better surface finish levels than C1119™/C1144™.

Preheating may be necessary prior to thermal cutting of free-machining steels.

Thermal Cutting

Because of the higher sulfur levels, additional care must be used when thermal cutting these steels to avoid cracking (stress cracks). This often necessitates preheating and post-heating, depending on grade and thickness. The publication "Guidelines for Fabricating and Processing Plate Steel" provides guidelines on the procedures to be used. Important guidelines are summarized in Table 2.

Table 2
Thermal Cutting Guidelines for Free-Machining Steels

	Type	Thickness (Inches)		
Specification	A-Alloy C-Carbon	+50°F Min. Plate Temp (1)	Preheat 300°F Gas Cut Hot	Preheat 300°F Gascut Hot Immediately (2) HT Edges (3)
Clean-Cut® 20	C	2 and under	Over 2	-
C1119™	C	2 and under	Over 2	-
Clean-Cut® 45	C	-	1 and under	Over 1
C1144™	C	-	1 and under	Over 1
4140	A	-	1 and under	Over 1
4142	A	-	1 and under	Over 1
4150	A	-	-	All thickness
8620	A	8 and under	-	-
MTD® #1	A	-	1 and under	Over 1
MTD® #2	A	-	1 and under	Over 1
MTD® #4	A	-	-	All thickness

Notes to Table 2:

Recommended practices are based on Tables 10 and 11, "Iron and Steel Society Steel Products Manual – Plate" and/or ArcelorMittal USA's experience.

1. When preheating is not required, plates should be at a temperature of at least 50°F. During winter months, plates brought in from outside storage may require several days to warm up, depending on thickness.
2. Edges must be heat treated immediately after cutting to soften edges. If unable to heat treat edges immediately, material must be kept hot until heat treated.
3. Heat to 1100°F/1325°F, hold 1/2 hr./in., air cool. An anneal or sub-critical anneal may be substituted.

Heat Treating

ArcelorMittal USA's free-machining steels may be heat treated when proper care is utilized. The 0.45% carbon and alloy grades are inherently sensitive to "quench cracking" problems. Therefore, parts machined with holes or significant changes in cross-section may require packing and generous fillets. Surface hardening treatments, such as flame hardening, should also be done carefully because a heating torch may etch out sulfide inclusions, providing sites for cracking on the surface. Refer to "Guidelines for Fabricating and Processing Plate Steel" for further information.

Welding

ArcelorMittal USA's Clean-Cut® and C1119™/C1144™ steels are not intended for structural purposes. However, welding may be required on occasion. Because of the higher sulfur levels, special care should be used, including the use of:

- Low hydrogen processes and consumables
- Low sulfur weld metals
- Low strength weld metals
- Low to moderate arc energy/heat input
- Preheat suitable for the chemistry and thickness of the plate

Note: these resulfurized steels will exhibit a greater propensity for lamellar tearing in highly restrained welded joints.

Surface Treatments

Processes that require precise cleaning of a finished steel surface, such as acid etching for chrome plating, should be evaluated prior to full scale processing. Sulfide inclusions on the finished part surface may etch out, leaving surface indications.

Further Information

1. "MTD & Tool Steels" product brochure
2. "Guidelines for Fabricating and Processing Plate Steel", 2000
3. "Plate Steel Specification Guide"
4. Contact Alex Wilson at T +1 610 383 3105 or email at alex.wilson@arcelormittal.com.

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