



Plate

BethStar®: Low-Carbon, Control-Rolled, High-Strength Steel Plate for improved toughness, weldability and formability

Introduction

BethStar® steel plate delivers a lower applied cost than carbon steel

The BethStar family of low-carbon, control-rolled, high-strength steel plate offers improved toughness, weldability and formability when compared to competitive grades, such as ASTM A572.

Four grades – BethStar 50, 60, 70 and 80 – enable design engineers to take advantage of the increased strength levels and fabricating advantages these plate grades offer. BethStar plates combine outstanding toughness, ease of fabrication and attractive strength/cost relationships, which can translate into real savings for the end user.

The BethStar plate grades meet the requirements of ASTM A656, Type 7 (modified to 0.010 maximum sulfur).

Improved formability provides easier fabrication and saves “redos”

The excellent formability of the four BethStar grades is associated with low sulfur (0.010 max) and the relative absence of stringer manganese sulfide-type inclusions and the refined grain size resulting from control-rolling. The suggested minimum inside bend radii for forming BethStar and recommended procedures and precautions are shown in Table 3.

Table 1
Description

BethStar Grades	Min Yield (ksi)	Min Tensile (ksi)	Min% Elong. in 8"	Notch Toughness* Min CVN Longitudinal	Max Avail. Thickness
50	50	60	18	15 ft-lb @ -50°F	2-1/2 in.
60	60	70	17	15 ft-lb @ -50°F	1-1/4 in.
70	70	80	14	15 ft-lb @ -50°F	1 in.
80	80	90	12	15 ft-lb @ -50°F	3/4 in.

* More restrictive toughness requirements are available on inquiry.

Table 2
Availability

Thickness (in.)	Maximum Widths (in.)			
	BethStar 50	BethStar 60	BethStar 70	BethStar 80
1/4**	132	132	84	84
> 1/4 to 3/8	144	144	96	96
> 3/8 to 3/4	150	150	96	96
> 3/4 to 1	150	150	96	-
> 1 to 2-1/2	144	144	-	-

Maximum lengths depending on thickness and width range from 1,440 in. to 420 in.

** Thickness 3/16 to < 1/4 in. available on inquiry.

Improved weldability reduces need for preheat and saves money

BethStar 50, 60, 70 and 80 are readily weldable using conventional arc welding processes. Specified base metal strength and toughness can be maintained into the weld zone, provided proper weld consumables and normal levels of heat input are used.

These grades have low-carbon contents, low-carbon equivalents and exhibit excellent resistance to hydrogen-assisted cracking. Normally, preheating is unnecessary for temperatures as low as 0°F, provided low-hydrogen conditions can be maintained. When base metal temperature is below 32°F, the plate should be preheated to remove any moisture.

Fatigue properties

Fracture and fatigue are best controlled by proper methods of design, fabrication and inspection. The BethStar grades exhibit fatigue properties typical of High Strength Low Alloy (HSLA) grades of similar strength levels. For specific information on BethStar 80, refer to page 8.

Table 3
Minimum Inside Radius for Transverse Bends
(T=Thickness)

Thickness (in.)	BethStar 50	BethStar 60	BethStar 70	BethStar 80
1/4	1T	1T	1T	1T
> 1/4 to 3/4	1.5T	1.5T	1.5T	1.5T
> 3/4 to 1	1.5T	1.5T	1.5T	-
> 1 to 2-1/2	2T	2T	-	-

Precautions for bending all BethStar grades

The following precautions should be taken for severe bending operations:

1. The largest radius permissible should be used.
2. Major bends should be made on a line that is perpendicular to the length of the plate (rolling direction), if possible.
3. The outside radius should not be restrained. Closed-die forming may require doubling the suggested radii to avoid breakage.
4. Sharp notches on the edge of plates, resulting from shear breaks or torch cutting, require removal by grinding or machining to prevent cracking during severe forming.
5. Roll forming of cylindrical sections should be preceded by crimping of the butt edges before forming.
6. Extremely severe forming should be done hot, after heating the plate to 1100°F max.

BethStar® Characteristics

- Four grades, in a wide range of thicknesses, make precise specification a simple matter.
- Low carbon and sulfur provide improved formability, weldability and toughness-reducing costs in processing.
- Higher strength/cost ratios deliver lower applied costs.

Table 4
Characteristics of Grades 50, 60, 70 and 80

Grade	Max Thickness Availability ¹	Chemical Composition ²							Carbon Equivalent ³ IW	Min Preheat ⁴ For Temp. 0°F	CVN Toughness ⁵ Min Longitudinal	Relative ⁶ Cost	Yield Strength ⁷ Relative Cost
		C Max	Mn Max	P Max	S Max	V Max	Cb Max	Si Max					
50	2-1/2 in.	.10	1.40	.025	.010	.10	.06	.35	.27-.31	None	15ft-lb @ -50°F	1.21	40.6
60	1-1/4 in.	.10	1.40	.025	.010	.10	.06	.35	.28-.32	None	15ft-lb @ -50°F	1.25	47.2
70	1 in.	.10	1.65	.025	.010	.10	.06	.35	.30-.34	None	15ft-lb @ -50°F	1.29	53.4
80	3/4 in.	.16	1.65	.025	.010	.10	.06	.40	.37-.41	70°F	15ft-lb @ -50°F	1.33	59.2

Footnotes:

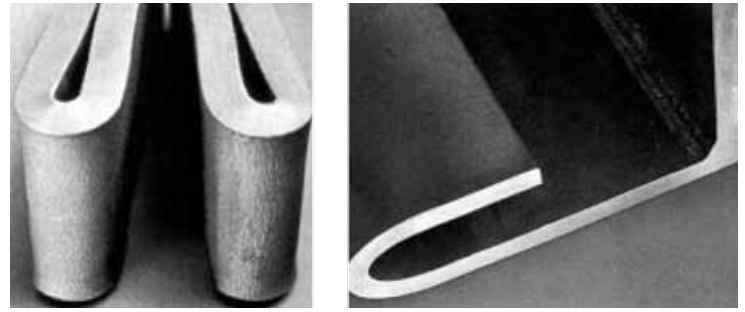
1. Thicknesses 3/16 in. to 1/4 in. are available on an inquiry basis. If thicker plates are needed, please inquire with ArcelorMittal.
2. Composition values shown are maximums. BethStar plates may be ordered to more restrictive sulfur levels at additional cost.
3. Carbon equivalent values are used to compare relative ease of welding. The tabulated values correspond with the typical range most commonly used for plates produced by ArcelorMittal. The commonly used International Institute of Welding Carbon Equivalent (IIW C.E.) is based on the empirical equation:

$$CE = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15}$$

For steels with lower carbon contents, the P_{cm} equation has been found to be a better representative of the contribution of chemical composition, where:

$$P_{cm} = C + \frac{Mn+Cu+Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + \frac{Si}{30} + \frac{Ni}{60} + 5B$$

Figure 1
Examples of BethStar's excellent formability



4. For grades 50, 60 and 70, no preheat is required for temperatures above 0°F, provided low hydrogen conditions are maintained. For grade 80, at temperatures below 32°F, base metal should be heated to at least 70°F.
5. More restrictive Charpy V Notch (CVN) values are available on an inquiry basis at additional cost.
6. Relative costs are based on A36 steel plate (3/4 in. x 96 in. x 240 in. = 1) and are expressed as a ratio.
7. *Yield Strength to Relative Cost* Relates cost of minimum yield in ksi of various grades. The higher the number, the more advantageous to the designer, for example:

For A36

$$\text{Yield Strength} = 36 = 36$$

$$\text{Relative Cost} = 1.00$$

For BethStar 50

$$\text{Yield Strength} = 50 = 41$$

$$\text{Relative Cost} = 1.23$$

BethStar® 50

BethStar 50 plate has 50 ksi minimum yield strength and is available in thicknesses up to 2-1/2 in. Its outstanding toughness makes it an economical replacement for normalized grades in many applications. It may be ordered to conform to ASTM A656 or A808 specifications. BethStar 50 is ideal for fabrications where formability, weldability, strength and toughness are essential. Potential applications requiring excellent toughness include construction and mining equipment frame components or large crane and offshore fabrications involving highly constrained weldments.

The BethStar family includes a minimum CVN toughness of 15 ft-lb longitudinal at -50°F. It may be ordered to even more restrictive specifications at additional cost. Table 5 and Figures 3 and 4 demonstrate the yield, tensile and CVN characteristics of BethStar 50 over a range of thicknesses. The superior toughness obtainable through additional chemistry and processing refinements is clearly seen in Figure 2.

Figure 2
Representative properties of normal and superior toughness of BethStar 50

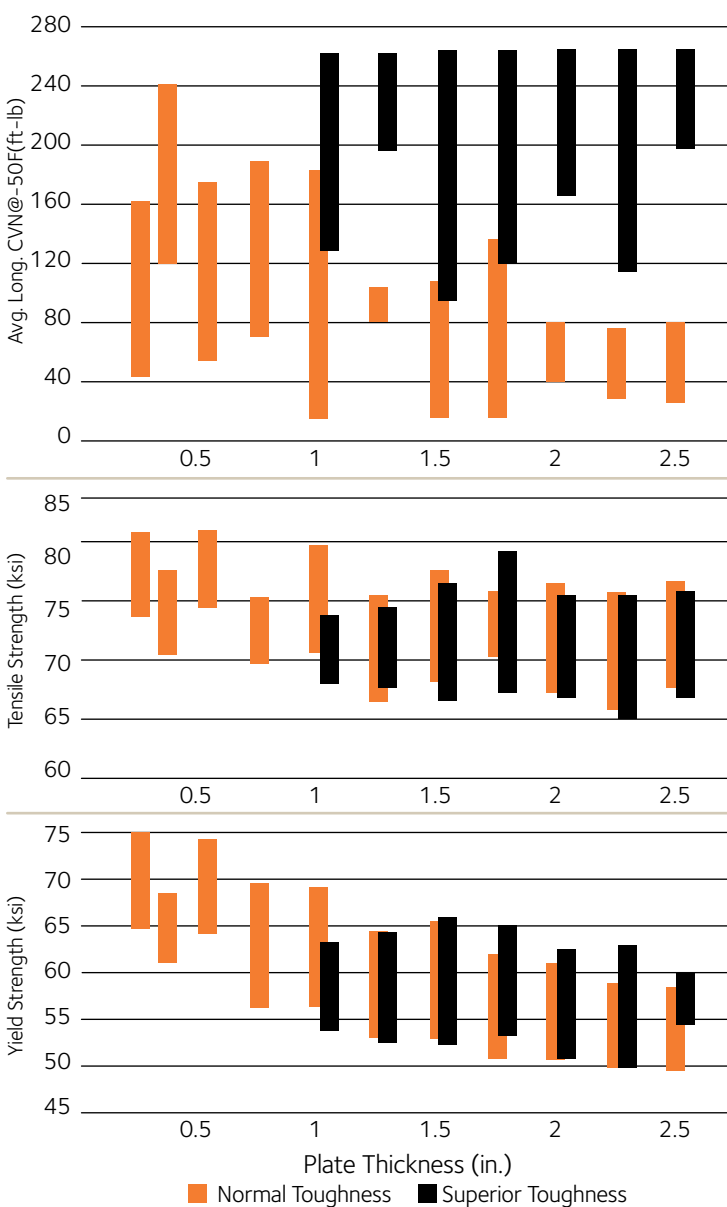


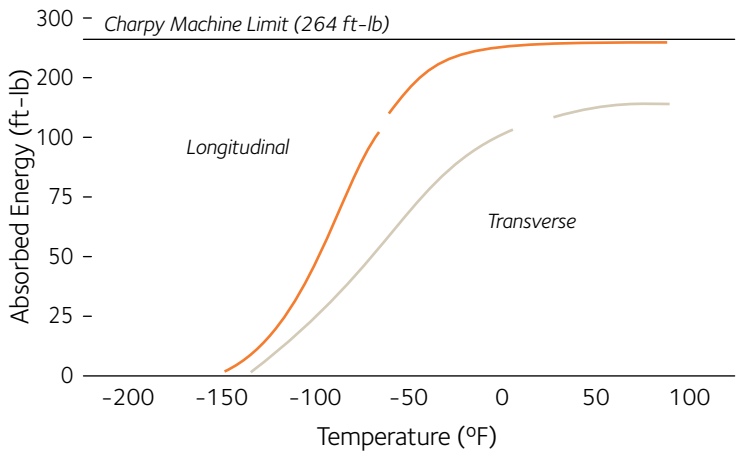
Table 5
Representative mechanical properties of BethStar 50*

Thickness (in.)	Avg. Yield Strength (ksi)	Avg. Tensile Strength (ksi)	Avg. % Elong.	Longitudinal Charpy V Energy (ft-lb @ -50°F)	
				Normal	Superior
3/8	64.5	73.9	34.5 (2")	136 (3/4 size)	-
1	62.2	70.8	24.9 (8")	81	170
1-1/2	58.7	72.8	27.0 (8")	61	202
2	55.1	71.9	30.3 (2")	60	225

* Based on production tests of over 100 plates.

Figure 3
Longitudinal and transverse full curve Charpy impact data for superior toughness BethStar 50 plates

Graph A – BethStar 50 – 1/2 in. (13 mm)



Graph B – BethStar 50 – 1 in. (25 mm)

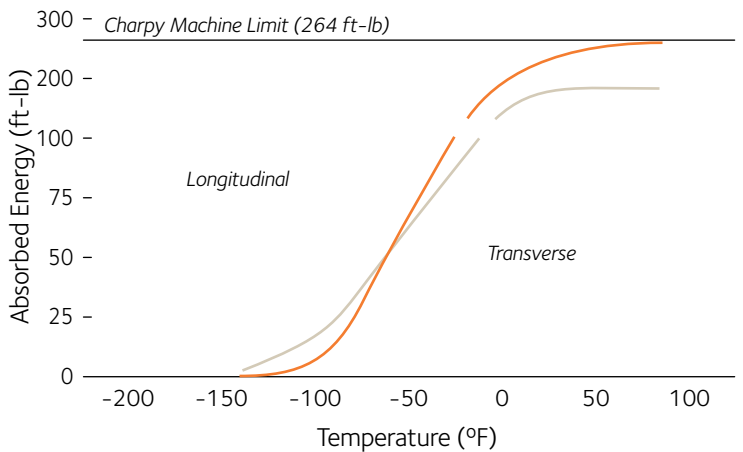
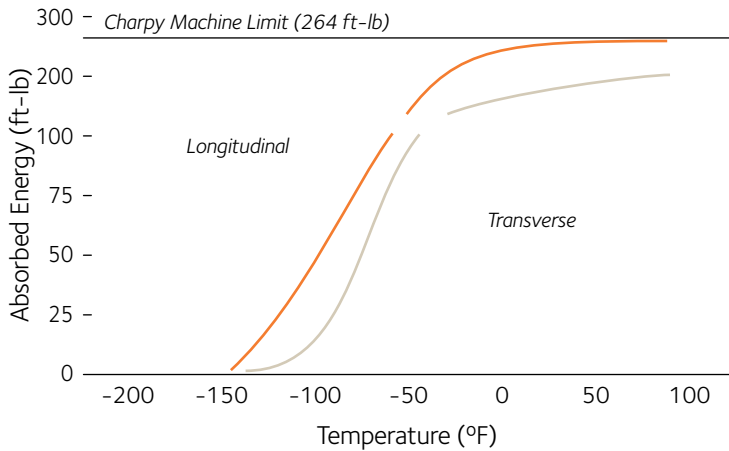


Figure 4
Longitudinal and transverse full curve Charpy impact data for superior toughness BethStar 50 plates

Graph A – BethStar 50 - 1-1/4 in. (32 mm)



Graph B - BethStar 50 - 2 in. (50 mm)

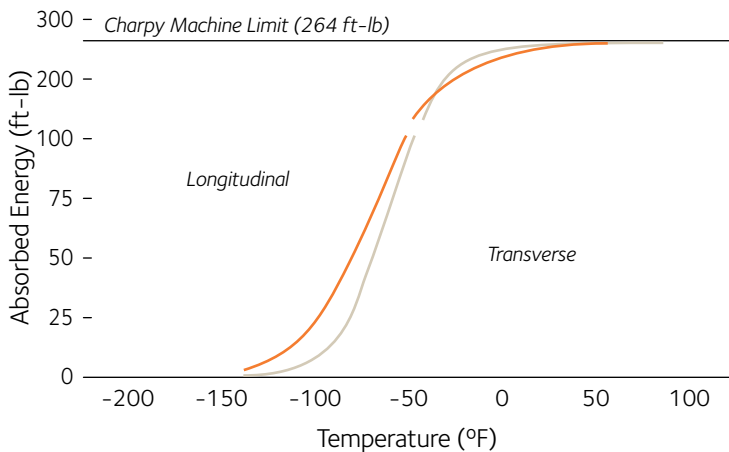
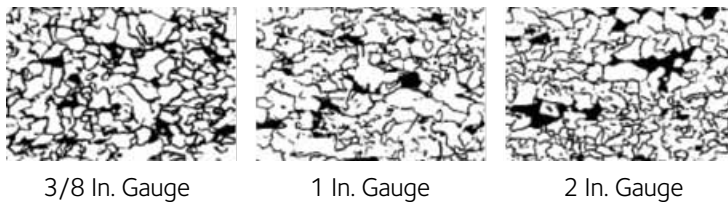


Figure 5
Representative microstructures of BethStar 50 plates at an original magnification of 200X



Metallography

The BethStar 50 combination of microalloying and thermomechanical processing typically produces ferrite/pearlite microstructures with a fine ferritic grain size ranging from ASTM 10 to 12. A fine-grained duplex grain size, elongated ferrite grains, warm-worked ferrite, and occasional bainite/martensite patches may also be observed. The grain refinement results from the interaction between alloying and low-finish temperature control rolled processing.

The columbium microalloying inhibits austenite recrystallization and below a critical temperature, the rolling deformation becomes cumulative. As a result, a pancaked austenite grain morphology is obtained during rolling, which produces a very fine ferrite grain size after transformation.

A fine, uniform ferrite grain size is the key to improved strength, toughness and formability for BethStar plate.

Welding Suggestions

BethStar 50 is readily weldable and normally will require no preheat for temperatures above 0°F, provided low-hydrogen conditions can be maintained. When base metal temperature is below 32°F, the plate should be preheated to remove any moisture.

Consumables

Manual Shielded Metal Arc Welding. Any low-hydrogen (EXXX15, 16 or 18) electrode of the E70 strength level or above.

Submerged Arc Welding. Many electrodes falling under the general classification F10X-EXXX will provide welds with adequate strength.

More detailed specifications are necessary if impact properties are required.

Gas Metal Arc Welding. An electrode meeting AWS specifications ER70S-1 will provide strength and toughness sufficient for this grade.

Flux Cored Arc Welding. An electrode meeting AWS A5.29 specification E7XT-X, except -2, -3, -10 or -GS will provide adequate strength and toughness for this grade.

Procedural Testing

For production applications where strength and toughness are critical, weld procedural tests should be made to simulate actual joints.

Figures 6, 7 and 8 indicate the excellent balance of strength and CVN toughness maintained across the welded joint.

For additional reference information on welding procedures, see pages 8 and 9 for evaluations of BethStar 80.

Figure 6
Transverse Charpy impact data for base metal and HAZ of a submerged arc welded 1-1/4 in. (32 mm) BethStar 50 plate.

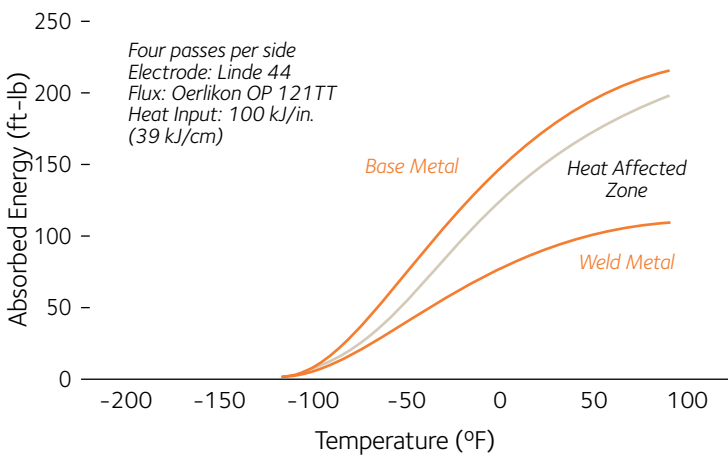


Figure 7
Hardness traverse across a submerged arc welded 1-1/4 in. (32 mm) BethStar 50 plate.

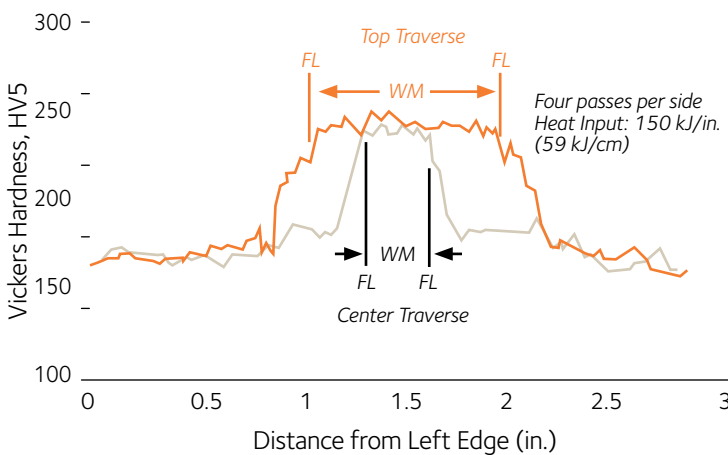
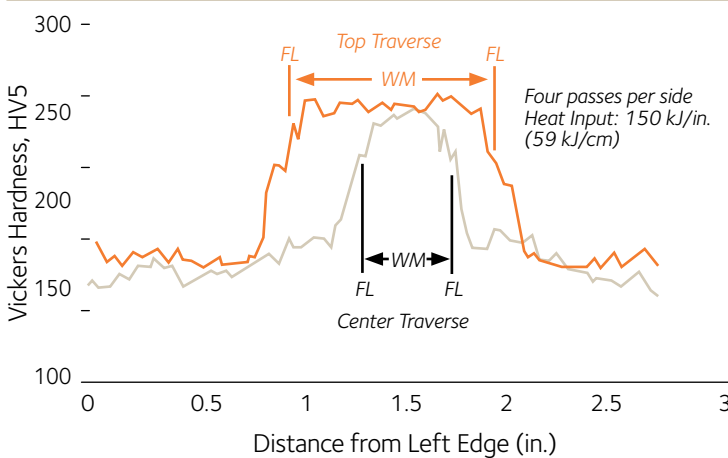


Figure 8
Hardness traverse across a submerged arc welded 2 in. (50 mm) BethStar 50 plate.



BethStar® 60

BethStar 60 plate has 60 ksi minimum yield strength and is available through 1-1/4 in. thickness. It combines an attractive strength/cost ratio with outstanding toughness, formability and weldability. It may be ordered to ASTM A656, Type 7 specification.

BethStar 60 provides the design engineer with a new option in an economical HSLA grade that is readily fabricated. Potential applications include weight-sensitive components subject to high stress, such as frames for large off-highway haulers.

Metallography

The microstructure of BethStar 60 displays a uniformly fine grain structure, which is essentially a combination of ferrite and pearlite with an ASTM ferrite grain size of 10 or finer. In general, the ferrite grain size increases with plate thickness, but overall is quite consistent with a range of only one ASTM number.

However, as the plate thickness increases, there is deformation into the two-phase region, which produces elongated and deformed ferrite grains.

Table 6
Representative mechanical properties of BethStar 60*

Thickness (in.)	Avg. Yield Strength (ksi)	Avg. Tensile Strength (ksi)	Avg. % Elong.	Longitudinal Charpy V Energy (ft-lb @ -50°F) (3/4 size)
3/8	69.0	78.4	39.7 (2")	134
1/2	69.0	77.5	42.9 (8")	98
1	72.4	84.6	25.9 (8")	91

* Based on production tests of over 40 plates.

Figure 9
Longitudinal and transverse full curve Charpy impact data for 1/2 in. (13 mm) BethStar 60 plate

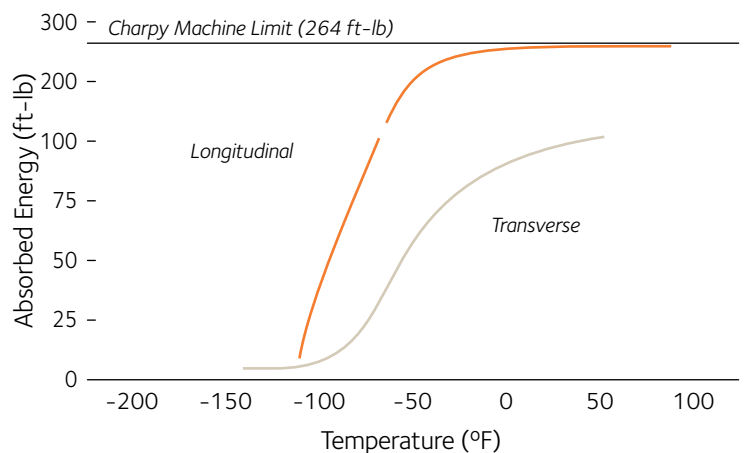


Figure 10
Representative microstructure of BethStar 60 plates at an original magnification of 200X – 1 in. (25 mm)



Welding Suggestions

Like all of the BethStar family, BethStar 60 is readily weldable, and requires no preheat for temperatures above 0°F, provided low-hydrogen conditions can be maintained. When base metal temperature is below 32°F, the plate should be preheated to remove any moisture.

Consumables

Manual Shielded Metal Arc Welding. Any low-hydrogen (EXXX15, 16 or 18) electrode of the E80 strength level or above.

Submerged Arc Welding. Many electrodes falling under the general classification F10X-EXXX will provide welds with adequate strength. More detailed specifications are necessary if impact properties are required.

Gas Metal Arc Welding. An electrode meeting AWS specification ER80S-1 will provide strength and toughness sufficient for this grade.

Flux Cored Arc Welding. An electrode meeting AWS A5.29 specification E7XT-X, except -2, -3, -10 or -GS, will provide adequate strength and toughness for this grade.

Procedural Testing

For production application where strength and toughness are critical, weld procedural tests should be made to simulate actual joints. For additional reference information on welding procedures, see pages 8 and 9 for evaluations of BethStar 80.

BethStar® 70

BethStar 70 plate has 70 ksi minimum yield strength and is available through 1 in. thickness. High strength, outstanding strength/cost ratio, and ease of fabrication make it a logical replacement for many alloy and heat-treated grades.

BethStar 70 is an ideal grade where strength/weight ratios are important in complex fabrications for critical applications. Potential applications include cantilevered components such as excavator booms, front-end loader hoist arms, or dump body frame components. It may be ordered to ASTM A656, Type 7 specification.

Metallography

The microstructure of BethStar 70 plate is essentially a combination of ferrite and pearlite. Figures 12A and 12B illustrate representative microstructures for 1/2 in. and 1 in. plates at an original magnification of 200X. The material is extremely fine grained, with a typical ferrite grain size of ASTM 10 or finer.

Welding Suggestions

BethStar 70 is readily weldable and requires no preheat for temperatures above 0°F, provided low-hydrogen conditions can be maintained. When base metal temperature is below 32°F, the plate should be preheated to remove any moisture.

Consumables

Manual Shielded Metal Arc Welding. Any low-hydrogen (EXXX15, 16 or 18) electrode of the E90 strength level or above.

Submerged Arc Welding. Many electrodes falling under the general classification F1 OX-EXXX will provide welds with adequate strength. More detailed specifications are necessary if impact properties are required.

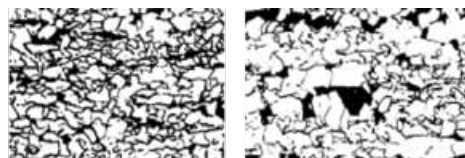
Gas Metal Arc Welding. An electrode meeting AWS specification ER90S-1 will provide strength and toughness sufficient for this grade.

Flux Cored Arc Welding. An electrode meeting AWS A5.29 specification E8XT-X, except -2, -3, -10, or -GS, will provide adequate strength and toughness for this grade.

Procedural Testing

For production applications where strength and toughness are critical, weld procedural tests should be made to simulate actual joints. For additional reference information on welding procedures, see pages 8 and 9 for evaluations of BethStar 80.

Figure 11
Representative microstructures of BethStar 70 plates at an original magnification of 200X – 1/2 in. and 1 in.



1/2 In. Gauge

1 In. Gauge

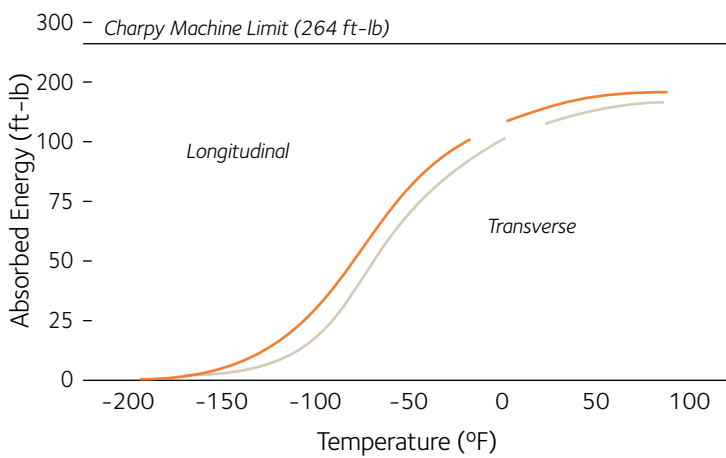
Table 7
Representative mechanical properties of BethStar 70*

Thickness (in.)	Avg. Yield Strength (ksi)	Avg. Tensile Strength (ksi)	Avg. % Elong.	Longitudinal Charpy V Energy (ft-lb @ -50°F)
1/4	78.3	85.5	18.3 (8")	62 (1/3 size)
1/2	78.2	85.9	17.7 (8")	66
1	75.2	87.2	19.1 (8")	56

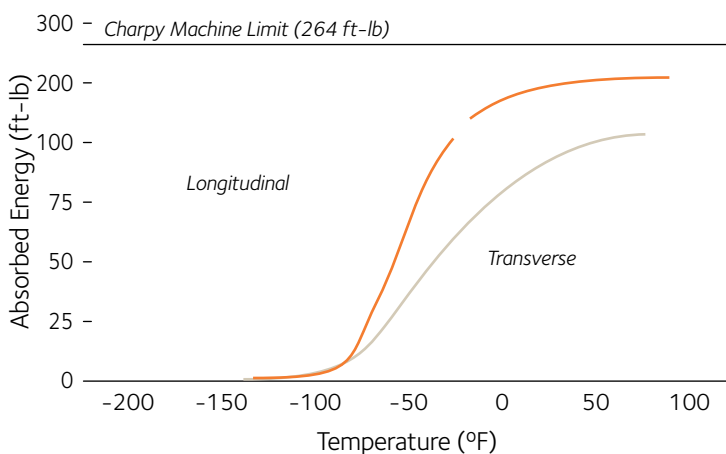
* Based on production tests of over 30 plates.

Figure 12
Longitudinal and transverse full curve Charpy impact data for BethStar 70 plates

Graph A – BethStar 70 - 1/2 in. (13 mm)



Graph B - BethStar 70 - 1 in. (25 mm)



BethStar® 80

BethStar 80 plate has 80 ksi minimum yield strength and is available through 3/4 in. thickness. Its outstanding strength/cost ratio, toughness and ease of fabrication have made it the designers' choice for a wide variety of structural components. Applications include rough terrain crane booms and outriggers, off-highway hauler dump bodies and canopies, roll-over structures and on-highway trailer frames.

The excellent notch toughness of BethStar 80 is shown in Figure 13. These plates exhibit excellent fracture appearance, as well as high-energy values at sub-zero temperatures. They may be ordered to ASTM A656, Type 7 specification.

Fatigue Properties

Strain-cycle fatigue tests were conducted on specimens machined from 1/4 in. thick plate. The testing was conducted according to ASTM E606-80, "Recommended Practice for Constant Amplitude Low-Cycle Fatigue Testing." Test specimens were prepared with a 0.15 in. square reduced section and a surface finish of 16 rms. The results in Figures 14 and 15 are typical of fatigue properties for other steels with a tensile strength of about 100 ksi.

The properties and parameters determined for the cyclic stress-strain curve and cyclic strain-life relationship can be used to calculate fatigue performance for various notched conditions. Further details on this approach can be found in "Fatigue Under Complex Loading," *Advances in Engineering*, Vol. 6, published by SAE, Inc., 1977, Warrendale, PA.

Welding Suggestions

BethStar 80 plate is readily weldable using the conventional arc welding processes as reflected by its low-carbon and sulfur contents. Normally, preheating will be unnecessary; however, when the base metal temperature is below 32°F, the base metal should be preheated to at least 70°F, and this minimum temperature should be maintained during welding.

Table 8
Representative mechanical properties of BethStar 80*

Thickness (in.)	Avg. Yield Strength (ksi)	Avg. Tensile Strength (ksi)	Avg. % Elong. in 8 in.	Charpy Size	Avg. Transverse Charpy V Energy (ft-lb @ -40°F)	Avg. Longitudinal Charpy V Energy (ft-lb @ -20°F)
3/16	90.1	100.8	18.9	1/3	22.5	27.6
1/4	87.5	98.1	19.2	1/2	38.6	48.3
3/8	86.9	99.0	18.2	3/4	41.2	73.0
1/2	90.4	102.4	17.8	Full	36.9	92.2
5/8	86.7	98.6	18.7	Full	38.2	73.5

* Based on production tests of 500 plates.

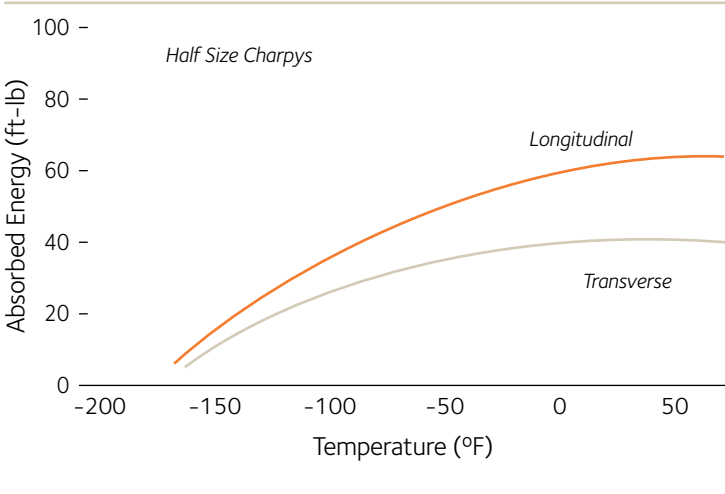
Consumables

Manual Shielded Metal Arc Welding. Any low-hydrogen (EXXX15, 16 or 18) electrode of the E100 strength level or above will give adequate strength. If notch toughness is a prime requirement, E10018M can be used. The American Welding Society's "Specification for Low-Alloy Steel Covered Arc-Welding Electrodes," AWS A5.5-69, discusses these electrode classifications.

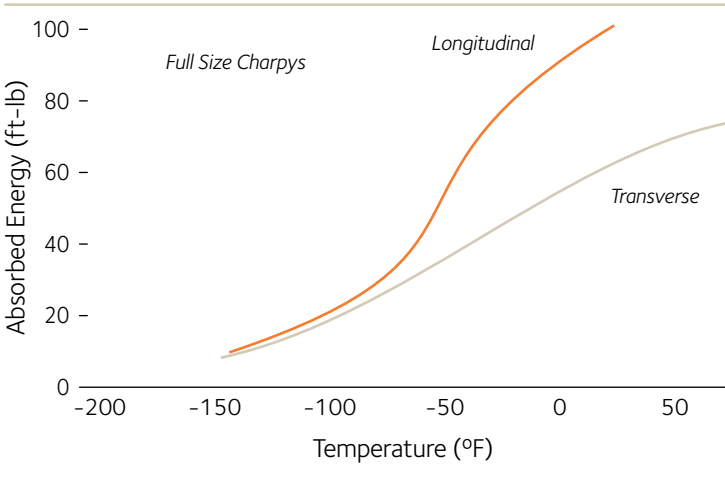
Submerged Arc Welding. The AWS booklet, "Specification for Base Low-Alloy Steel Electrode and Fluxes for Submerged Arc Welding," A5.23-76, prescribes requirements for electrode/flux combinations for submerged arc welding. While many electrodes falling under the general classification and F10X-EXXX will provide welds with adequate strength, more detailed specifications are necessary if impact properties are required (for example, Linde 95 wire + 709-5 flux will conform to AWS grade F106-EM2-M2, which specifies 20 ft-lbs, at -60°F).

Figure 13
Longitudinal and transverse full curve Charpy impact data for BethStar 80 plate

Graph A – BethStar 80 - 1/4 in. (6 mm)



Graph B – BethStar 80 - 1/2 in. (13 mm)



Gas Metal Arc Welding. AWS publication, "Specification for Low-Alloy Steel Filler Metals for Gas-Shielded-Arc Welding," AWS A5.28-79, gives requirements for GMAW electrodes. An electrode meeting AWS specification ER100S-1 will provide weld metal strength and toughness sufficient for this grade.

Flux Cored Arc Welding. An electrode meeting AWS A5.29 specification E100T1-K3 or E100T1-K5 will provide adequate strength and toughness for this grade.

Procedural Testing

For production applications where strength and toughness are critical, weld procedural tests should be made to simulate actual joints.

Procedure plates have been welded on 1/4 in. and 1/2 in. plates at heat inputs of nominally 35 and 50 kJ/in. Tensile and bend results have been satisfactory. Figure 16 is a comparison of impact properties in the weld metal, the weld heat-affected zone (HAZ), and the base materials. As shown, an excellent balance of toughness is maintained across the welded joint. Hardness traverses, as shown in Figures 17 and 18, made on the 1/4 in. and 1/2 in. plates, show good uniformity across the welded joint.

Figure 14
Cyclic stress-strain curve for 0.25 in. (6 mm) plate

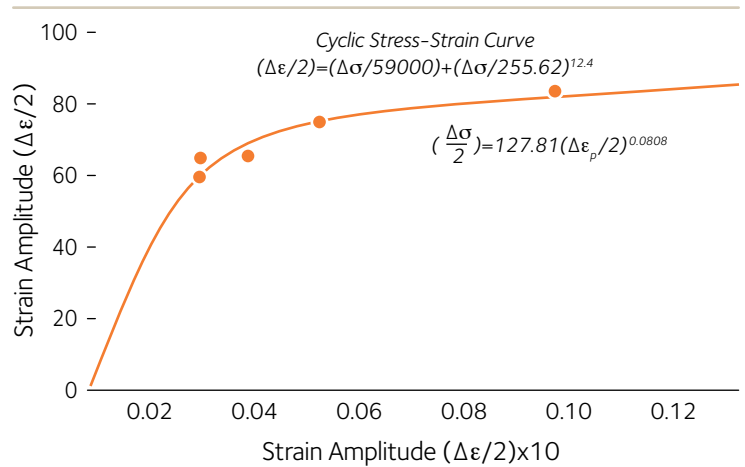


Figure 15
Strain-life curve for 0.25 in. (6 mm) plate

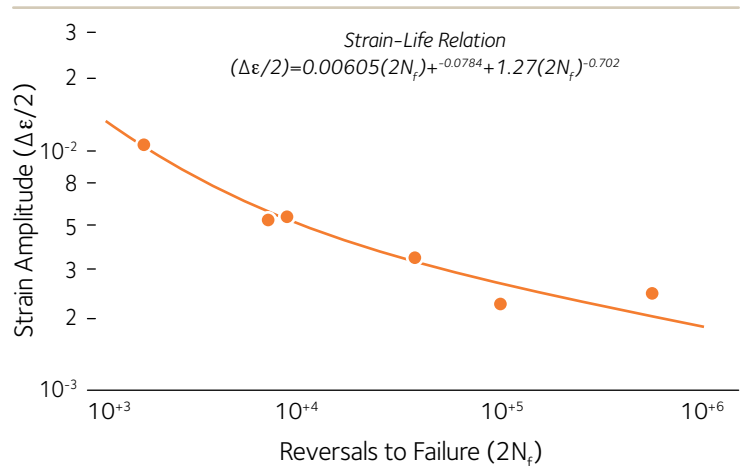
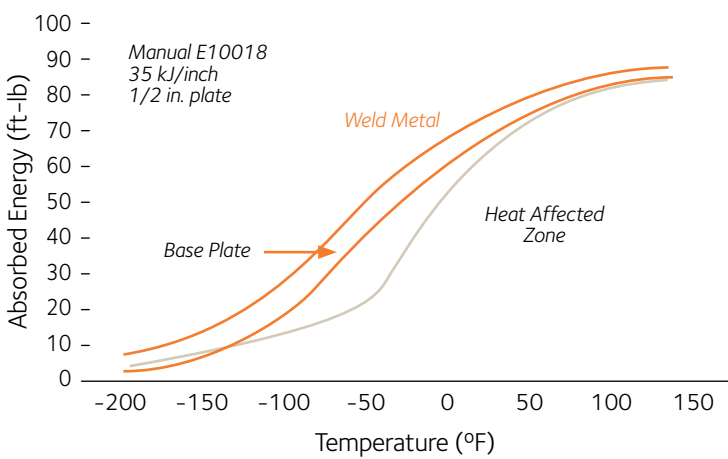


Figure 16
Full-size transverse Charpy impact curves for base plate, weld metal and heat-affected zone in 1/2 in. plate



Metallography

The microstructure of BethStar 80 plate is essentially a combination of ferrite and pearlite. The material is extremely fine grained with a typical grain size of ASTM 12 and finer.

Straining, Aging and Stress-Relieving Effects

BethStar 80 responds to cold straining in much the same manner as other materials. Small amounts of strain result in modest increases in strength and modest decreases in ductility and notch toughness. Aging after straining results in slight further emphasis on these changes. Proper stress relief annealing will essentially restore the original notch toughness and tensile properties.

Formability

The excellent formability of BethStar 80 is associated with low sulfur content and the relative absence of stringer manganese sulfide-type inclusions. Figure 1 (page 2) shows 3/8 in. plate that was bent to a 1/2 T bend radius, and no evidence of failure can be seen.

BethStar 80 plate can be readily formed at room temperature if adequate power is available and proper procedures are followed. The suggested minimum inside radius for forming the 80,000 psi yield strength plate, as a function of thickness, is given in Table 3 (page 1).

Figure 17
Hardness traverse across weld at the root and face of the weldment in 1/4 in. (6 mm) plate

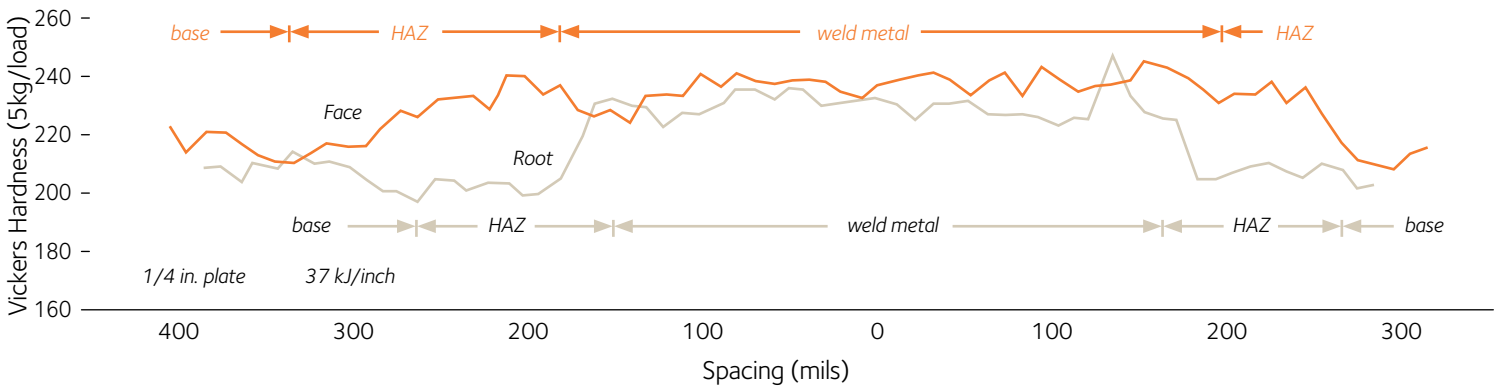


Figure 18
Hardness traverse across weld at the root and face of the weldment in 1/2 in. (13 mm) plate

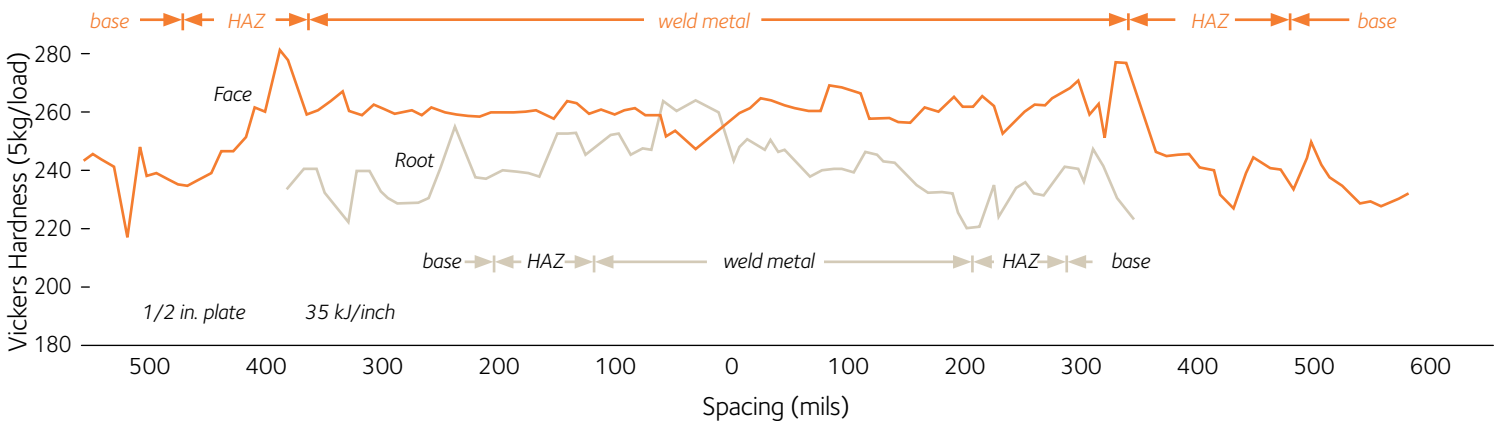


Table 9**Effects of straining, aging and stress-relieving on tensile and Charpy properties of 1/4 in. (6 mm) thick plates (transverse data)**

Condition	0.2 Pct Yield Strength (psi)	Ultimate Tensile Strength (psi)	Elong. in 2 in. (%)	Reduc. in Area (%)	CV ^{7.5} °F	1/2 Size Charpy Specimens			
						FATT 50°F	40°F	0°F	Energy (ft-lb) +32°F
As-rolled	91,800	94,000	21.0	58.5	-140	-120	32	35	36
Strained 5%	100,500	104,000	21.5	62.0	-105	-100	32	36	36
Strained 5% one hour @ 550°F	111,300	113,700	15.4	56.8	-95	-90	24	28	29
Strained 5% aged @ 550°F for one hour and stress relieved for one hour @ 1100°F	90,800	99,800	25.0	57.5	-115	-115	25	28	29

Important

The information provided herein is based on testing or ArcelorMittal experience and is accurate and realistic to the best of our knowledge at the time of publication. However, characteristics described or implied may not apply in all situations. ArcelorMittal reserves the right to make changes in practices which may render some information outdated or obsolete. In cases where specific properties are desired, ArcelorMittal should be consulted for current information and/or capabilities.

Further Information

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Continuing updates of this information can be found on our website at: www.arcelormittal.com.

All information in this brochure is for the purpose of information only. ArcelorMittal USA reserves the right to change its product range at any time without prior notice.

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