



Pre-Coated or Uncoated Low Carbon, Heat-Treatable Boron Steel

1 Scope

This specification covers the requirements for low carbon, heat-treatable boron steel used in the manufacture of structural parts to manage very high tensile loads without significant deformation such as required in safety and occupant protection. This material is heat treated, formed and simultaneously quenched in a water-cooled die in a process referred to as hot stamping, hot press forming or press hardening. Material produced by this process is generally referred to as Press Hardened Steel (PHS). This process produces parts with a microstructure consisting of primarily tempered martensite with allowable trace amounts (less than 5%) of non-martensitic transformation products. PHS parts may also be specified to contain soft zones, which are lower strength than the surrounding metal and may not be fully martensitic in structure.

1.1 Material Description. The material designation is defined by the GMW material specification number, material category (Sheet or Tubular product), steel product type, grade, and finish type. The substrates used in these applications may be cold rolled or hot rolled, but the product type is designated as heat treated (HT) or hot stamped (HS), as appropriate. The steel grades will correspond to the chemical and mechanical requirements as shown in Table 2 and Table A1 through Table A3. Only the surface quality designation of U, representing an unexposed application, shall be used unless otherwise approved by Materials Engineering. The preceding descriptive items are used together to form the coding system. Examples of the coding system for engineering part drawings, electronic math data files and/or manufacturing engineering documents are shown in Section 8.

1.1.1 Resistance Welded Mechanical Tubing. Tubes supplied to this specification are formed from a steel strip to the desired shape and dimension, electrical resistance welded into a tube, and then heat treated to achieve the final mechanical property requirements.

1.1.2 Induction Heat Treated Steel. Part sections formed with this operation and supplied under this standard shall be made by stamping in the as-rolled condition. The raw stamping can be selectively induction hardened to achieve the required strength requirements. Al-Si, Zn, Zn-Fe, or Zn-Ni pre-coated products shall not be used in these applications.

1.1.3 Hot Stamped Die Quenched Steel. Parts shall be made by austenitizing a pre-cut blank, hot stamping the heated blank and rapid cooling (quenching) the stamped part in the die or via water quenching. Press hardened steel (PHS) can be formed by either direct or indirect stamping processes. The direct process is considered as main-stream for all usages (except tubes). The indirect process is less common and more expensive since it requires two dies and is not compatible with common oven designs and press systems.

Note: The indirect stamping process is not a globally available manufacturing process and must not be used (or parts designed to require its use) without the prior authorization of the GM Global Functional Lead (GFL). Use of the indirect process implies that affected parts cannot be used globally without driving excessive cost to ship stamped parts globally. Exception: For tubular products such as axle tubes, the indirect process is globally available and can be used without prior approval.

1.1.3.1 Uncoated Products. Parts formed with uncoated steel and supplied under this standard shall be subsequently cleaned (also referred to as "blasting") to mechanically remove oxide from the surface as described in 3.3.3.2.

1.1.3.2 Pre-Coated Products. Parts formed with a hot stamping operation may also utilize pre-coated steels furnished according to this specification in order to eliminate the need for cleaning/blasting and/or to improve corrosion performance.

1.1.3.2.1 Aluminum-Silicon (Al-Si) Pre-Coatings. Al-Si coated parts shall not be cold-stamped prior to the hot stamping operation, but roll-forming or variable thickness rolling operations may be allowable if the coating is not significantly damaged and approved by GM Materials Engineering. As noted in GMW15619, paragraph titled

Hot Stamped AlSi-Coating, variable thickness rolled blanks are restricted to non-corrosion-critical areas, and use in corrosion critical areas must be approved by GM Materials Engineering.

Cleaning/blasting is not permitted for Al-Si pre-coated parts to prevent damage of the coating.

1.1.3.2.2 Zinc Based Pre-Coatings. The preferred manufacturing process for zinc or zinc alloy coated parts is direct hot stamping, parts shall be cleaned (blasted) to remove any oxide layer from the surface as described in 3.3.3.2.

1.1.4 Material Call-Outs. The list of material and coating designations shown in Table 1 are the only approved material call-outs that can be released unless Materials Engineering and the appropriate Global Subsystem Leadership Team approves.

Table 1: Approved Material Call-Outs

Material Call-Out	Coating System	Material Description
GMW14400M-ST-S-HS1300T/950Y-MS-UNCOATED-U	Uncoated	Uncoated press hardened steel stampings
GMW14400M-ST-S-HT1475T/1170Y-MS-UNCOATED-U	Uncoated	Uncoated induction heat treated products
GMW14400M-ST-T-HT1475T/1170Y-MS-UNCOATED-U	Uncoated	Uncoated welded and heat treatable tubular product
GMW14400M-ST-S-HS1300T/950Y-MS-AS60G60G-U	Al-Si	Al-Si coated press hardened steel stampings
GMW14400M-ST-S-HS1300T/950Y-MS-AS35G35G-U	Al-Si	Al-Si coated press hardened steel stampings
GMW14400M-ST-T-HT1475T/1170Y-MS-AS60G60G-U	Al-Si	Al-Si coated welded and heat treatable tubular product
GMW14400M-ST-S-HS1300T/950Y-MS-EG60N60N-U	Zn-Ni	Zn-Ni coated press hardened steel stampings
GMW14400M-ST-S-HS1300T/950Y-MS-HD80A80A-U	Zn-Fe	Hot dip Zn-Fe coated press hardened steel stampings

1.2 Symbols. Not applicable.

1.3 Applicability. Typical applications are uncoated or pre-coated sheet metal stampings and thin gauge tubular structural parts requiring tensile strengths exceeding 1300 MPa. Typical applications include door impact beams, bumper impact beams and structural reinforcements for side impact and roof strength.

1.4 Remarks. See Table B1 in Appendix B for cross-referenced/superseded specifications.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

ASTM A370	ASTM E45	ISO 3887	JIS Z2241
ASTM A428	ASTM E112	ISO 4287	SAE J419
ASTM A513	ASTM E1077	ISO 6892	SAE/USCAR-5
ASTM A751	EN 10346	ISO 18594	SAE/USCAR-7
ASTM B487	ISO 1460	ISO/TS 16949	VDA 238-100

2.2 GM Standards/Specifications.

GMW8	GMW14057	GMW14829	GMW15619
GMW3011	GMW14058	GMW14872	GMW16170
GMW3059	GMW14700	GMW15200	GMW16549
GMW3224	GMW14704	GMW15282	GMW16579
GMW3335	GMW14729	GMW15425	

2.3 Additional References.

- GWS-5A
- SEP 1160 (Available at <http://www.stahleisen.de> → Go to Products → Bookshop)
- SEP 1970 (Available at <http://www.stahleisen.de> → Go to Products → Bookshop)

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- VDA 238-100 (Available at <http://www.vda.de/en> → Services → Publications)

3 Requirements

This section defines specific requirements for material on delivery, processing, performance and other stages during life cycle. Deviations required for individual GM business units are listed in the Deviations at the end of this document.

Parts supplied according to this specification shall undergo successful trials that fully meet end product requirements. In the event of any changes to the heat treatment and/or manufacturing process to which the part was successfully validated, the appropriate engineering group must be notified, and the part must be tested and requalified to the proper Production Part Approval Process (PPAP) level as determined by GM.

Hot stampers are required to maintain a consistent source of steel supply and to use GM approved suppliers listed in GM's MATSPC system.

3.1 Sample Requirements for Qualification. For initial steel supplier qualification, test samples shall be removed from production representative coils and heat treated in a production representative manner. If the samples are either zinc coated or uncoated, the surfaces shall be media blasted in a production representative process to remove surface oxides.

3.2. Engineering Requirements.

3.2.1 Chemistry. Base metal composition based on product (coil, or sheet/blanks) analysis determined per ASTM A751 shall conform to the requirements of Table 2 and/or shall be agreed upon between supplier and purchaser. When end product (coil/blank) test results are not available, ladle analysis may be used. Chemical composition on the end product is the referee method.

Table 2: Chemical Composition, Mass % ^{Note 1}

	Press Hardened Stampings	Straight Tubes
Carbon	0.19% to 0.24%	0.19% to 0.27%
Manganese	1.00% to 1.50%	1.00% to 1.50%
Aluminum	≥ 0.010%	≥ 0.010%
Silicon	≤ 0.50%	≤ 0.50%
Phosphorous	≤ 0.030%	≤ 0.030%
Sulfur	≤ 0.005%	≤ 0.005%
Chromium	≤ 0.35%	≤ 0.35%
Titanium	0.020% to 0.055% ^{Note 2}	0.020% to 0.055%
Nitrogen	≤ 0.010%	≤ 0.010%
Boron	0.0005% to 0.004%	0.0005% to 0.004%

Note 1: See Table Dev 1 in the Deviations Section for high hardenability alloy chemistry.

Note 2: To ensure boron protection, titanium must exceed stoichiometry with respect to nitrogen ($Ti > 3.42 N$).

3.2.2 Applied Process Coatings.

3.2.2.1 Corrosion Preventatives. Temporary/transit corrosion protection, such as oils, paper, or containerization, etc., may be used to protect the coils or blanks from in-transit corrosion that may result in detrimental impact to subsequent manufacturing processes. Rust preventatives applied to finished parts shall be chosen so as to not contaminate paint systems or negatively affect subsequent manufacturing operations.

3.2.2.2 Forming Lubricants. If coil or blank lubricants are applied, supplier shall ensure that all downstream operations, manufacturing processes and part performance requirements are not negatively affected. Lubricants shall not be a source of diffusible hydrogen into the steel when burned during austenitization. Any lubricant applied must pass all qualification tests outlined in this specification.

3.2.3 Mechanical Property Requirements. The 0.2% Offset Yield Strength, Tensile Strength and Percent Total Elongation shall be determined in the longitudinal direction per GMW3335. Tests shall be performed using samples per ISO 6892 Type I (50 mm gage length ASTM type sample), ISO 6892 Type II (80 mm gage length DIN type sample), or JIS Z2241 (No. 5). See Note 3 and Note 4 in Table A3 for deviations relative to testing standard tensile bars with material gauges less than 1 mm and subsize tensile bars with specimen gauge lengths less than 50 mm.

3.2.3.1 Base Metal Mechanical Property Requirements. Cold rolled steel supplied to this specification for direct hot stamping operations shall be in the "full hard" or non-annealed condition and hot rolled steel shall be supplied with "as rolled" mechanical properties unless otherwise agreed upon. Steel supplied for induction heat treating after forming shall conform to the pre-heat treat requirements in Table A2.

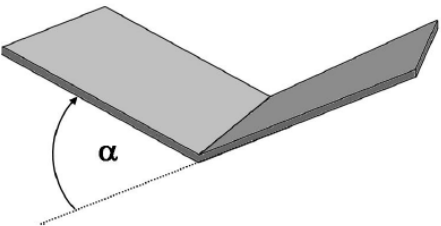
3.2.3.2 Finished Part Mechanical Property Requirements. All finished parts shall meet the mechanical property requirements shown in Tables A1, A2 or A3 depending on the specific application and manufacturing process. Suppliers are responsible to ensure that the method used to cut and prepare tensile specimens for evaluation shall be appropriate for the strength of the material.

If a part is to contain soft zones, they shall be specified in the part math file and shall contain the locations, size/transitions and mechanical properties of the soft zone(s).

3.2.4 Bend Test Requirements. Bend testing is required for steel supplier qualification. Samples shall be taken from production representative coils and heat treated in a production representative process.

Bend testing shall be performed according to VDA 238-100. The material shall be capable of being bent without pre-strain, both longitudinally and transverse to the rolling direction, through the bend angle, α , as shown in Table 3 on a three point free bend with the ends unrestricted with bending radii shown in Table 3.

Table 3: Bend Radius and Minimum Bend Angle per VDA 238-100

	Sheet Thickness	Bending Radius	Force Shutoff Criterion	Bending Angle, α :
	$t \leq 1.2 \text{ mm}$	$r = 0.4 \text{ mm}$	30 N	≥ 50 degrees at maximum bending force
	$1.8 \text{ mm} \geq t \geq 1.2 \text{ mm}$	$r = 0.4 \text{ mm}$	30 N	≥ 45 degrees at maximum bending force
	$2.0 \text{ mm} \geq t \geq 1.8 \text{ mm}$	$r = 0.4 \text{ mm}$	30 N	≥ 40 degrees at maximum bending force
	$t \geq 2.0 \text{ mm}$	$r = 0.4 \text{ mm}$	60 N	≥ 40 degrees at maximum bending force

3.2.4.1 Bend Test for Heat Treated Parts. Heat treated parts shall meet the bend test requirements as described in 3.2.4 as part of the prototype part validation and initial part production verification by saleable PPAP. Samples shall be removed from finished parts using laser, water jet cutting, or electrical discharge machining (EDM). If a suitably sized sample for bend testing per VDA 238-100 cannot be removed from the part, flat samples from the production material may be heat treated and die quenched in the production representative process according to the supplier's process control plan, or waived by GM Engineering or GM Supplier Quality.

3.2.4.2 Hydrogen Embrittlement Sensitivity. All materials supplied to this specification must be free of hydrogen embrittlement according to SEP 1970 (U-bend test or tensile specimen with notched hole loaded to 100% yield strength (YS)) or SAE/USCAR-7 (standard tensile specimen loaded to 80% ultimate tensile strength (UTS)). Hydrogen generating processes including, but not limited to, acid cleaning, phosphating, electroplating, etc., shall be avoided whenever possible. In the case where hydrogen generating processes cannot be avoided for steel and/or part processing, suppliers shall follow the de-embrittlement requirements per SAE/USCAR-5

followed by verification that parts are free of hydrogen embrittlement per SEP 1970 or (SAE/USCAR-7) in the preceding manner. For direct water part processing (quenching), suppliers shall follow the de-embrittlement requirements per SAE/USCAR-5 and verify parts are free of hydrogen embrittlement per SEP 1970 (tensile specimen with notched hole loaded to 100% YS) or SAE/USCAR-7 (standard tensile specimen loaded to 80% UTS).

3.2.5 Additional Requirements for Pre-Coated Steels for Hot Stamping. The following requirements shall be met by steel suppliers and stampers of pre-coated boron steels used in hot-stamping applications. These requirements are in addition to the chemical and mechanical requirements in Table 2 and Table A3.

3.2.5.1 Coating Analysis Prior to Heat Treatment. The continuous coating shall meet the composition requirements in Table A4 or Table A5 and shall also meet the requirements of GMW3059. The coating shall not contain trace elements that are detrimental to adhesive bonding, phosphate or other conversion coatings applied to promote paint adhesion, or paintability.

3.2.5.2 Coating Mass Prior to Heat Treatment. ASTM A428, ISO 1460 or EN 10346 shall be used for determination of coating mass for coatings. The test sample size shall be 2000 mm² minimum, with a preferred sample size of 3330 mm² (57.7 mm ± 0.1 mm or 65.1 mm ± 0.1 mm in diameter). Coating mass shall be measured by triple spot and single spot testing, and shall conform to values in Table A4 or Table A5. The triple spot coating mass shall be an average of three measurements taken across the width of the strip at least 25 mm from the edge. In no instance shall the coating weight of any of these samples fall below the minimum single spot test requirement in Table A4 or Table A5. Each side shall be measured separately (e.g., by masking the coating from one side) to ensure the requirements of Table A4 or Table A5 are met.

3.2.5.3 Coating Analysis After Heat Treatment (Qualification and PPAP). For zinc-based coatings, a Glow Discharge Optical Emission Spectroscopy (GD-OES) analysis, or equivalent, must be performed through the coating thickness for both steel supplier qualification and initial part production verification by saleable PPAP. The coating composition, including the elements iron, zinc, nickel, aluminum and manganese shall be reported along with photomicrographs at 500x from both sides of the steel sheet.

For Al-Si coatings, a Glow Discharge Optical Emission Spectroscopy (GD-OES) analysis, or equivalent, must be performed through the coating thickness for steel supplier qualification. The coating composition, including the elements iron, aluminum, silicon, and manganese shall be reported along with photomicrographs at 500x from both sides of the steel sheet.

Processing and handling of the coated product during heat treatment and any other processes shall not contaminate the coating. See GMW16579 for process related contamination of the coating.

3.2.5.4 Coating Thickness After Heat Treatment. Coating thickness requirements are shown in Table A4 and Table A5. Photomicrographs of Al-Si coating cross sections following heat treatment are shown in Figure A1. Interdiffusion layers are identified in Figure A1 to outline the measurement method. Coating thickness may also be used for routine quality control evaluations. Coating thickness is measured using a suitable layer thickness gauge, on-line x-ray gauge, or from a specimen cut perpendicular to the panel surface per ASTM B487. Suitable instruments for evaluation of coating thickness on the as-received pre-coated sheet (e.g., eddy current, ferromagnetic, or metallurgical microscope) shall have a capability of ± 1.0 µm accuracy. Magnetic inductive measurements are not recommended on the finished hot-stamped part without proper calibration due to the alloy reaction which occurs during hot stamping. When using a metallurgical microscope to examine the coating layers, standard mounting practices shall be used and thickness shall be measured after 2% to 4% nital etching followed by examination at 500x to 1000x magnification.

3.2.6 Cyclic Corrosion Lab Test in Flanges (Qualification Testing). Samples for corrosion testing shall be prepared according to SEP 1160, part 1, glass flange type II "Evaluation of Weldable Corrosion Protection Primers for the Automotive Industry – Corrosion Performance" and as shown in Figure 1. No paint is allowed on the flanged surfaces. The paint used to coat the surface outside of the flange (non-test surfaces of the panels) is not required to meet original equipment manufacturer (OEM) specifications, however, the applied paint must remain fully adherent during corrosion testing and prevent corrosion of the painted surfaces.

Three samples representing each side of the material shall be prepared with simulated glass flanges for a total of six samples. In addition, three reference samples with coatings HD60G60G or EG60G60G shall be prepared and evaluated in the same way. The samples shall then be exposed to accelerated laboratory corrosion testing according to GMW14872 (UB), All, 4sp, Method 1/2, Exposure D. Maximum pit depth shall be determined by microscopic cross section of the flange section, taking care to examine the entire area under the flange. Corrosion pit depth shall be comparable or less than the reference zinc coated samples.

Assembly of Glass Flanges for Corrosion Tests

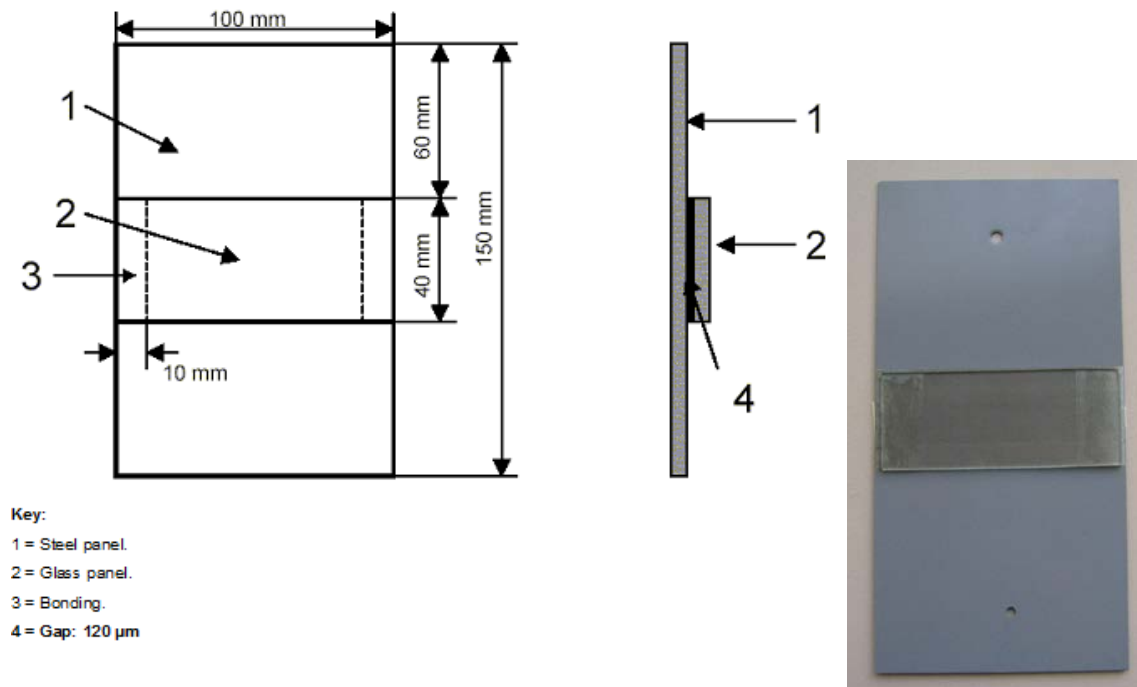


Figure 1: Sample Setup for Corrosion Test with Flanges

3.2.7 Coating Adhesion (Qualification Testing). Coating adhesion is evaluated on degreased samples that have been adhesively bonded and subsequently evaluated by lap shear strength testing as described in GMW15200-HS-IR-FS with a GM-approved high strength impact resistant full spectrum adhesive. Samples shall be prepared and evaluated to represent standard cure condition (25 minutes at $175\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$). The bond strength and fracture mode of the samples shall be reported.

Cohesive separation within the adhesive (preferred) or delamination of the coating to the steel substrate that occurs above the specified minimum strength level of $\geq 16\text{ MPa}$ at room temperature and $\geq 8\text{ MPa}$ at $-40\text{ }^{\circ}\text{C}$, are considered acceptable.

3.2.8 Microstructure.

3.2.8.1 Inclusions. Non-metallic inclusions in the steel substrate shall be quantified according to ASTM E45 Method D, Plate I-r, by analysis at 100x; inclusion content shall not exceed a rating of 2 for thin and 2 for heavy.

3.2.8.2 Prior Austenite Grain Size. For both coated and uncoated steel, a prior austenite grain size rating ($16\text{ }\mu\text{m}$ – rating of ASTM 9 or finer per ASTM E112) may be specified for impact critical hot-stamped components as determined by GM Materials and Product Engineering.

3.2.9 Material Thickness and Tolerances. The detailed engineering part drawing or electronic math data file will specify the material thickness. Thickness tolerances shall be per GMW3224. Tolerances for electric resistance welded tubes not specified on drawings shall follow ASTM A513.

3.2.10 Coating Designation. The type of coating and coating mass is specified by a suffix added to the basic specification number. The first two letters AS will designate a continuous Al-Si pre-coating. The letters HD will designate a continuous hot-dipped zinc (with suffix G after coating mass callout) or zinc-iron alloy (with suffix A after coating mass callout) pre-coating. The letters EG will designate a continuous electrolytically-applied zinc (with suffix G after coating mass callout) or zinc-nickel (with suffix N after coating mass callout) pre-coating. The coating mass prior to hot stamping for each side is designated in grams per square meter (g/m^2). Only the specified coating masses of Table A4 or Table A5 (triple spot and single spot) may be used unless the appropriate engineering group is consulted. The letter U follows the coating and mass designation to specify an unexposed surface finish. See examples of nomenclature in Table 1 and Table 4. Developmental coatings are shown in Table A6.