

NAVISTAR, INC.		
Material, Parts, and Process Specifications (MPAPS)		NUMBER: MPAPS E-10
		Former Designation: CEMS E-10
TITLE: Ductile (Nodular) Iron Castings		CURRENT REV No.: 1504
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<i>This specification may involve hazardous materials, equipment, and procedures. This specification does not purport to address all of the safety issues associated with its use. The user is responsible to consult appropriate safety and health practices and to determine the applicability of regulatory limits prior to use.</i>		
Change Notice: Added tensile requirements to Table II; changes to the microstructural requirements for Si-Mo Ductile Iron; added references to ASTM E689; editorial changes.		

1.0 SCOPE

This specification covers the Company's requirements for castings made of ductile iron (also known as nodular or spheroidal graphite iron). Ductile irons may be used in the as-cast condition, or when design considerations require improved properties may be heat treated.

2.0 INTRODUCTION

Ductile iron (DI) is a versatile material with strength similar to cast steels but with castability and machinability similar to gray iron. The most economical is making parts from as-cast grades. Annealed, ferritic DI grades offer lower strength with the best ductility and toughness. Higher strength in the unalloyed ductile iron grades is obtained by normalizing (pearlitic) or by quenching and tempering (martensitic). These heat treatments provide increased strength with a subsequent reduction in ductility and toughness.

Austempered ductile iron (ADI) grades are produced by giving conventional ductile iron a special austempering heat treatment that makes them twice as strong as pearlitic ductile iron, but allows them to retain high elongation and toughness. ADI grades provide superior wear resistance and fatigue strength compare to conventional ductile iron. Their matrix microstructure consists of acicular ferrite and carbon stabilized austenite.

High Temperature Ductile Iron - To meet the demands of service conditions that are too severe for conventional or austempered ductile irons, ferritic ductile irons with high silicon-molybdenum levels have been added. The high silicon levels, combined with molybdenum, give the ferritic ductile irons superior mechanical properties at high temperatures and improved resistance to high temperature oxidation.

2.1 Restricted Chemical Substances

Effective January 1, 2007, all product supplied to the requirements of this specification must comply with the requirements of the MPAPS B-50 specification.

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4.0 REFERENCE DOCUMENTS

Unless otherwise specified, the latest issue of all referenced standards shall apply. The following standards, specifications and regulations are referenced in this specification.

Quality System Standard <i>ISO 9001 or TS-16949</i>	CFR Title 29, Part 1910	ASTM E 8
NAVISTAR Mfg Std. MS-D-13	ASTM A 247	ASTM E 10
NAVISTAR MS-K-13	ASTM A 536	ASTM E 71
NAVISTAR EPS-91	ASTM A 897	ASTM E 446
NAVISTAR EPS-143	SAE J434	ASTM E 94
MPAPS B-50	ASTM E 351	ASTM E 1999
SAE J2582	ASTM E 689	

5.0 CLASSIFICATION

5.1 Conventional Ductile Iron grades are classified on the basis of its strength, hardness, and microstructure. For manufacturing control purposes, the five conventional grades of ductile iron described in this specification (see Table II) are based primarily upon hardness.

5.2 Austempered Ductile Iron grades (see Table III) are classified based on their tensile properties and elongation.

5.2 High Temperature Ductile Iron grades (commonly known as Si-Mo Ductile Iron) are classified based on chemical composition, hardness and microstructure (see Table IV).

6.0 GENERAL REQUIREMENTS

6.1 Chemical Composition

The primary intent of this specification is to obtain castings with mechanical properties meeting specified minimum requirements. The chemical requirements shown in Table I for ductile iron are considered the minimum necessary controls to help maintain property requirements. However, other combinations of pearlite-stabilizing elements such as copper, tin, and antimony, may be used by agreement between the controlling design engineering department and the foundry. Unless otherwise agreed upon between the controlling design engineering department and manufacturer, no changes in the

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chemical requirements of Table I will be allowed. Additional chemical requirements may be specified by agreement between the manufacturer and the controlling design engineering department.

TABLE I - CHEMICAL COMPOSITION REQUIREMENTS FOR DUCTILE IRON *

<u>ELEMENT</u>	<u>PERCENT</u>	<u>ELEMENT</u>	<u>PERCENT</u>
CARBON	3.45-3.96	COPPER	0.80 max
SILICON	2.10-2.90	MANGANESE	0.60 max
PHOSPHORUS	0.05 max	TIN	0.01 max
CHROMIUM	0.10 max	ANTIMONY	0.005 max

* Sulfur content will not exceed 0.035%

6.1.1 Austempered Ductile Iron (ADI)

The composition of the iron used for ADI castings differs very little from conventional ductile iron. There are no specific chemical requirements for ADI beyond those shown in Table I. The properties of an ADI casting are primarily dependent upon the austempering heat treatment. However the chemistry and quality of the iron prior to austempering must be controlled. To avoid micro-segregation and degradation of mechanical properties associated with higher levels of manganese and molybdenum, these contents should be carefully controlled. The desired level of hardenability to achieve a fully bainitic structure is preferentially obtained by supplementary additions of copper (up to about 0.8%), and then nickel. However upon engineering approval of prototype parts and manufacturing approval of PPAP samples, no changes in the composition of the ADI iron used for approved parts is permitted without the approval of the controlling design engineering department and the receiving NAVISTAR plant.

6.1.2 High Temperature Ductile Iron (High Si-Mo DI)

These grades are alloyed DI grades. The concentrations of the alloying elements silicon and molybdenum shall be controlled as specified in Table IV. Non-mandatory ranges (%) typical for some other elements are:

Element	Typical ranges, %
Carbon ⁽¹⁾	3.00 - 3.80
Manganese	0.10 - 0.50
Phosphorus	0.050 max
Sulfur	0.035 max
Magnesium ⁽²⁾	0.025 - 0.060

- 1) Target will be determined by section thickness of the casting
- 2) Cerium and other rare earth elements may be substituted for a portion of it

Other elements, like copper, nickel, cerium and other rare earth metals, may also be present.

Chemical composition shall be determined from samples representative of the castings and in accordance with applicable portions of ASTM E 1999, ASTM E 351, or other applicable ASTM Test Methods. The chemical composition of high temperature ductile iron is such that the nil-ductility transition temperature is commonly at or above room temperature. Accordingly, and unlike general-purpose ductile iron castings, these castings may exhibit brittle fracture behavior if roughly handled.

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6.2 Mechanical Properties

6.2.1 Requirements for Conventional Ductile Iron Castings

Ductile iron castings (except ADI castings and Si-Mo DI) will conform to the requirements shown in Table II unless otherwise specified. Application of properties shown therein should be discussed with a Materials Engineer.

6.2.1.1 Hardness Range:

Castings of an individual part number will normally have a narrower hardness range than that shown in Table II. This narrower hardness range may be requested by Manufacturing for process control purposes. If a reduced hardness range is agreed upon by the plant and foundry, the controlling design engineering department should be notified so that hardness range can be shown on the Engineering drawing.

TABLE II - REQUIREMENTS FOR CONVENTIONAL DUCTILE IRON GRADES
(Typical Properties Shown in Appendix)

Grade Designation				Casting Condition/ Matrix Microstructure *	Brinell Casting Hardness HBW		Min. Tensile Requirements			
							Yield Strength ksi (MPa)	Tensile Strength ksi (MPa)	% Elong. 2 in. (50 mm)	
Navistar Grade	Replaced IH Grade	Obsolete IH Grade	Approx SAE J434 Grade		min	max			Test Bars	Castings
4318	-	-	D4018	fully annealed/ ferritic	143	183	40 (275)	58 (400)	18	16
4512	65-43-18	65-43-16	D4512	as cast, fully annealed, or subcritically annealed, ferritic-pearlitic	149	217	45 (310)	65 (450)	12	10
		65-45-15								
		65-42-10								
5006 **	80-50-06		D5506	as cast or normalized/ pearlitic-ferritic	174	255	50 (345)	73 (500)	6	5
	80-55-06									
6503 **	100-65-03	100-70-03	D7003	as cast or normalized/ pearlitic-ferritic	229	277	65 (450)	102 (700)	3	2
Q&T	-	-	DQ&T	liquid quenched and tempered/ martensitic	range as specified		Minimum properties as specified on drawing or per agreement between supplier and purchaser.			

* When part drawings specify optional grades or grades permitting optional casting conditions (as cast, fully annealed, etc.), the condition furnished will be agreed upon by the supplying foundry and the using manufacturing plant. The as-cast condition is the least expensive and should be used wherever possible. Suppliers of as-cast ductile iron must be approved by the using manufacturing plant.

** If, for special engineering reasons, normalizing is required, a suffix "N" will be added, e.g., 5006N or 6503N. Refer to the "Appendix" for design properties.

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6.2.1.2 Critical Castings:

Critical Castings are defined as any casting having a critical DFMEA failure mode severity of 9 or 10 and/or a component identified on “Critical Cast Component List” provided in Section A.0 at the end of this specification. An analysis plan shall be executed during the total product lifecycle of all critical castings as indicated in Section A.1 below. Evaluation of castings against criteria listed here and to other specified requirements shall be conducted during initial part development (DVP&R), production part approval (PPAP) and full production (Ongoing Control Plan).

Castings regarded as critical by Engineering should be noted as such on the part drawing with the critical sections and required minimum properties clearly indicated. When specific properties are required, they will be applicable to a standard test specimen machined from the casting at the section indicated. For hardness requirements at critical sections, alternate locations may be checked provided adequate correlation with the required areas has been established.

6.2.1.3 Modification of Drawing Requirements

It is the foundry’s responsibility to meet all requirements on part drawings or to initiate negotiations with the purchasing plant and the controlling design engineering department to amend the requirements.

6.2.2 Requirements for ADI Castings

Test samples representative of a given ADI grade will conform to the requirements shown in Table III, unless otherwise specified (see Appendix). These requirements apply to the test bars after the austempering heat treatment. The type of test coupons, dimensions, processing, etc., shall be as described in ASTM A 897. The procedure for producing test specimens shall be agreed upon between the manufacturing plant and the foundry supplier. Special requirements for ADI cast products (e.g., hardness, composition, surface finish, etc.) should be specified on the part drawing or purchase order.

TABLE III – TEST BAR REQUIREMENTS FOR ADI GRADES

NAVISTAR Grade Designation*	Minimum Tensile Strength (ksi)	Minimum Yield Strength (ksi)	Minimum Elongation 2 in (50 mm), %, in	Impact Energy (ft-lb)**	Typical Hardness*** HBW
125/80/10	125	80	10	75	269-321
150/100/7	150	100	7	60	302-363
175/125/4	175	125	4	45	341-444
200/155/1	200	155	1	25	388-477

* Conforms to grade designation per ASTM A 897 also.

** Based on testing of unnotched Charpy bars at 72 ± 7°F. Values given are the average of the highest three values of four tested samples. Refer to ASTM A 897.

*** Hardness is not a requirement; given for information only.

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6.3 Metallurgical Requirements

6.3.1 Conventional Ductile Iron Microstructure

6.3.1.1 Graphite Form

The graphite form will be essentially spheroidal with not less than 85% conforming to Types I and II and no more than a total of 15% of Types III, IV and VI per ASTM A 247. Types V and VII are prohibited. (See ASTM A 247, Plate I, for graphite types)

6.3.1.2 Carbides

Massive carbides, excessive carbon flotation, or other micro constituents which would be detrimental to engineering properties or normal processing, are prohibited. A maximum of 10% well distributed, fine carbides is permitted, provided machinability is not adversely affected.

6.3.1.3 Matrix Structure

The fully annealed grade, 4318, will have a minimum of 95% matrix ferrite. However, some centerline pearlite is permitted in heavy sections. Grade 6503N will not have less than 85% pearlite in the matrix.

6.3.2 Austempered Ductile Iron Microstructure

Graphite form and carbides will meet requirements of Sections 6.3.1.1 and 6.3.1.2, respectively; the austempering heat treatment should produce a bainitic matrix microstructure consisting substantially of acicular ferrite and austenite. Depending on cooling rate in some sections of the casting, pearlite or other high-temperature transformation products may be present. The maximum acceptable quantities of these micro constituents at various locations within the casting should be established by agreement between Engineering, the using plant, and the foundry supplier.

6.3.3 High Temperature Ductile Iron Microstructure (High Silicon and Molybdenum DI)

Graphite form shall meet the requirements of Sections 6.3.1.1. The minimum acceptable levels of ferrite in the matrix microstructure depends on Grade as shown in Table IV. For all grades, the remainder of the microstructure shall consist of uniformly distributed pearlite and non-networked carbides.

Table IV - Grades of High Temperature Ductile Iron

Grade	Hardness, HBW	Silicon %	Molybdenum%	% Ferrite, Minimum
1	187-241	3.50-4.50	0.50 max	75
2*	187-241	3.50-4.50	0.51-0.70	95
3	196-269	3.50-4.50	0.71-1.00	95

* Previously covered by EMS E10-5006

6.4 Heat Treatment

6.4.1 Conventional Ductile Iron

For ductile iron castings, grades 4318, 5006N, 6503N and Q&T must be fully austenitized during processing. For Grade 4318, the maximum stabilizing temperature will be 735°C (1350°F) during annealing.

6.4.2 Austempered Ductile Iron

ADI castings shall be heat treated by an austempering process consisting of heating the castings to a fully austenitic, homogeneous condition, cooling (at a rate sufficient to avoid the formation of pearlite) to a temperature above the martensite start temperature, and isothermally transforming the matrix structure.

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6.4.3 High Temperature Ductile Iron (High Si-Mo DI)

High temperature ductile iron may require and annealing heat treatment to achieve the specified microstructure, particularly Grades 2 and 3. Specific details of the annealing process shall be agreed upon in advance between the purchaser and the foundry.

7.0 QUALITY

7.1 Quality Condition

Castings will be free from injurious defects with a finish that is satisfactorily clean when inspected for the intended use. Unless otherwise specified, a commercial quality casting is defined as indicated below:

7.1.1 Machined Surfaces

Machined surfaces and tapped holes will be free of casting defects.

7.1.2 Casting Soundness

In general, soundness of the casting (except for Section 7.1.1) is expected to meet severity level 3 for categories A, B and C (all types) per ASTM E 446 and/or E 689, using Vol. II reference radiographs (1 MV X-rays and Iridium 192 radiation). Category D, E, F and G defects (per ASTM E 446 and/or E689) are not permitted. This definition does not imply that radiographic certification is required unless so stated on the engineering drawing or purchase order, but rather that a particular quality level is expected. For critical castings, soundness should be verified by sectioning sample castings from production.

NOTE: ASTM E 446 is intended for steel castings but is applicable to ductile iron for the defect types discussed above. ASTM E689 extends the application of E446 to Ductile iron and where differences are noted deference should be given to E689

7.1.3. Cast Surface

Casting surfaces will be free of scale and burned-in sand. Fins, gate pads and other extraneous cast-on parts will be removed unless otherwise agreed to by the using manufacturing plant. Castings will not be covered with any substance which would hide defects. Castings will not be painted unless specified.

7.1.4 Salvage

Salvage welding of ductile iron castings will be in accordance with Navistar Manufacturing Standard MS-K-13, available from Corporate Technical Standards. Weld repair of ADI and Si-Mo DI castings is not permitted without approval from the purchaser.

7.2 Certification

Upon request, the supplier will furnish test bars and/or certification that castings furnished comply with these specifications. The supplier will be capable of routinely providing statistical data showing that his casting process is in control and capable of meeting all specified requirements.

7.3 Process Parameters

Casting suppliers will not introduce changes in the chemical composition or foundry processing practices, once they have been established and the initial parts approved, without the approval of the controlling design engineering department. Casting suppliers will not subcontract parts to other foundries without prior approval of the using manufacturing plants.

8.0 METHODS OF TEST

8.1 Tensile Test

Tensile testing will be performed in accordance with ASTM E 8.

8.1.1 Tensile Test Samples– Conventional Ductile Irons

For conventional ductile iron, tensile bars machined from the castings will conform to the dimensions shown in ASTM A 536. Use of the standard round specimen per ASTM A 536 is preferred.

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8.1.2 Tensile Test Samples– ADI

For austempered ductile iron, tensile and unnotched Charpy impact test sample-types and dimensions will conform to the requirements of ASTM A 897. Charpy testing will be performed as per ASTM A 897.

8.1.3 Tensile Test Samples- High Si-Mo

Various grades of high temperature ductile iron will be poured into separate, standard test coupons or machined from the castings (in accordance with ASTM A 536). Use of the standard round specimen per ASTM A 536 is preferred

8.2 Hardness Test

The Brinell hardness test per ASTM E 10 (HBW) will be the standard hardness test.

8.3 Metallurgical Evaluation

Evaluation of graphite morphology will be in accordance with ASTM A 247. A 100-diameter magnification will be used in all evaluations of graphite morphology.

9.0 SOURCE APPROVAL AND QUALITY CONTROL

9.1 Supplier Requirements

All suppliers to NAVISTAR are required to be registered to ISO 9001 Quality System Requirements. NAVISTAR will also accept TS-16949 registration as long as the supplier can also fulfill all AIAG PPAP (Production Part Approval Process) documentation and approval requirements. Suppliers must maintain their certification with an accredited registrar and must furnish copies of registration certificates to their Corporate Buyer upon request.

9.2 Approval

Parts supplied against contracts or purchase orders citing this specification shall be equivalent in all respects to those samples which were approved by the purchaser. No changes in formulation or processing practices are permitted without approval. In the event that changes in material, properties, processing practices, construction, color, or labeling of the product are required, the supplier shall notify NAVISTAR Materials Engineering and Purchasing and Supplier Development of the proposed change(s). Test data indicating conformance to all requirements of this specification, test samples, and new or amended or updated Material Safety Data Sheet(s) (MSDS), in accordance with CFR Title 29, Part 1910 shall be submitted with the request for change.

9.3 Process Control

The supplier shall either perform and report results of tests on specific lots of parts produced using ISO 9001 or TS-16949 guidelines, or provide statistical evidence of the lot having been produced in a state of statistical control and with a process capable of providing all required properties. The part supplier and the quality control manager of the using NAVISTAR plant may determine testing and reporting requirements on specific products.

10.0 DESIGNATION ON DRAWINGS AND PURCHASE ORDERS

Material designation on drawings and purchase orders will show the NAVISTAR grade and other special requirements.

Examples: Ductile Iron, Grade 5006, MPAPS E-10

Ductile Iron, Grade 6503N, MPAPS E-10

Ductile Iron, Grade Q&T, MPAPS E-10, Quench and Temper to HBW ____ to ____

Austempered Ductile Iron, Grade 125/80/10, MPAPS E-10

High Temperature Ductile Iron, Grade 2, MPAPS E-10

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10.1 Identification of Castings

Identification refers to the processing agreed upon by the supplying foundry and the using manufacturing plant. The NAVISTAR grade(s) specified on the engineering drawing may permit other options. The location of the identification may be shown on the part drawing after discussion with the foundry, but if not specified will be selected so that the marking will not interfere with machining, service use or appearance. Markings should be of uniform size and appearance and should preferably be placed near each other. Castings will be identified by the foundry with the following information where design and size permit.

10.1.1 NAVISTAR part number

10.1.2 Navistar trademark shown in Engineering Procedural Standard EPS-143, available from Corporate Technical Standards

10.1.3 Identification mark of the producing foundry

10.1.4 A casting date code as outlined in Engineering Procedural Standard EPS-91, available from Corporate Technical Standards

10.1.5 A casting code (grade and processing) as specified in Table IV.

TABLE IV: CASTING CODES

<u>Grade</u>	<u>Processing</u>	<u>Code</u>
4318	Annealed	4F
4512	as cast	4C
4512	subcritical annealed	4S
4512	Annealed	4A
5006	as cast	5C
5006N	Normalized	5N
6503	as cast	6C
6503N	Normalized	6N
Q&T	Quenched and tempered	5Q
125/80/10	Austempered	A1 or ADI1
150/100/7	Austempered	A2 or ADI2
175/125/4	Austempered	A3 or ADI3
200/155/1	Austempered	A4 or ADI4

11.0 PACKING AND SHIPPING

Packing and shipping will be in accordance with Navistar Manufacturing Standard MS-D-13. Castings will be packed and shipped to the manufacturer in such a way as to arrive undamaged.

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12.0 TECHNICAL INFORMATION

For further information related to the technical content of this specification, contact:	Suppliers may purchase controlled copies of this specification by contacting:
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SECTION A.0 Critical Component List

Item	Alternative Description(s)	Function(s)	Typical Materials	Additional DVP&R Requirements
Mega Bracket	Support Frame Extension Front Spring and Radiator Support	Supports primary front suspension Provides mounting to secure steering gear Supports bumper Supports tow/recovery device Supports cooling module	NI 5006 ADI 125/80/10 ADI 150/100/7	Yes - Tow Loading Bench Test
Engine Crossmember	-	Supports engine front mounting Provides primary front end lateral and torsional support	NI 5006 ADI 125/80/10	-
Tow Pin Crossmember	Heavy Duty Bumper Crossmember Front Tow Crossmember	Provides front end lateral and torsional support Supports tow/recovery	NI 5006 ADI 125/80/10	Yes - Tow Loading Bench Test
Crossmember End Bracket	Suspension Crossmember End Bracket	Provides dimensional stability and structural support between frame rails and rear suspension	ADI 125/80/10	-
I6 Rocker Arm	-	Carries load from pushrod to valve	Nodular Iron	Yes - Engine tests
Exhaust Manifold	-	Supports turbo assembly	High Si-Mo Nodular Iron	Yes - Engine tests
Bed Plate (V8)	-	Support crankshaft under firing pressure Add Stiffness to crankcase assembly	Nodular Iron	Yes - Engine tests
Bearing Cap (I6)	-	Support crankshaft under firing pressure	Nodular Iron	Yes - Engine tests
Front Suspension Rear Shackle/Slipper Bracket	Frame Hanger, Support	Connects rear of (front or rear) leaf spring to frame rail May contain bushing Connects to either shackle bracket (shackle), or slides against spring leaf (slipper)	NI 5006 ADI 125/80/10	
Spring Hanger - forward, leaf spring	Frame Hanger, Support	Mounts front of (front or rear) leaf spring to frame rail Contains rubber bushing	NI 5006	

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<i>Item</i>	<i>Alternative Description(s)</i>	<i>Function(s)</i>	<i>Typical Materials</i>	<i>Additional DVP&R Requirements</i>
Spring Hanger - Rear Suspension	Frame Hanger, Support	Mounts front eye of Main Support Member to frame rail	NI 5006 ADI 125/80/10	Yes - key life test (3544131C2 only)
Front Cab Mount - Cab Side	Support, Cab Side	Connects cab to front isolator Typically has structural ribs with thin wall thicknesses	NI 5006 ADI 125/80/10	
Front Cab Mount - Frame Side	Support, Cab Side	Connects front cab isolator to frame rail May have structural ribs with thin wall thicknesses	NI 5006 ADI 125/80/10	

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