PCC ENERGY GROUP

P92 X10CrWMoVNb9-2


F276

INTRODUCTION

The current demand for improved power generation efficiency requires the development of advanced materials that can withstand severe environments, along with higher temperatures and higher pressures. Creep-strength enhanced ferritic (CSEF) steels such as P91 were developed to withstand the extreme operating conditions of ultra super critical (USC) power plants and subsequently P92 was developed to achieve better mechanical properties, or comparable mechanical properties, with reduction in wall thickness.

Wyman Gordon routinely supplies this grade of material globally to meet ASTM/ASME A/SA335 P92, Indian Boiler Regulations, and/or EN10216-2, which classifies this material as X10CrWMoVNb9-2.

CHEMISTRY

The P92 chemistry is shown in Table 1. P92 contains a W addition and a reduction in Mo content, compared to P91. This V-Nb-B microalloyed steel benefits from precipitation strengthening due to MX-type and M23C6-type precipitation which occurs during the tempering cycle.

Solid-solution strengthening comes from W and Mo, while W-rich Laves phase precipitation is associated with increased resistance to creep. Creep resistance is the ability of a material to withstand degradation at high temperature under a constant load; an important property in the application of power generation.

Creep resistance is measured by creep rupture strength. Wyman Gordon data for creep rupture strength and other mechanical properties are presented on the following pages.

MICROSTRUCTURE

The creep resistant P92 microstructure consists of a ferritic matrix in the form of tempered martensite, free of delta ferrite. An example of a typical P92 microstructure produced by Wyman Gordon is shown in Figure 1. Wyman Gordon normalizes and cools P92 to result in a 100% martensitic structure. The martensite is then tempered to promote carbide precipitation which results in an ideal strength and toughness combination.

Element	Composition, %
Carbon	0.07-0.13
Manganese	0.30-0.60
Phosphorous	0.020 max
Sulfur	0.010 max
Silicon	0.50 max
Chromium	8.50-9.50
Molybdenum	0.30-0.60
Tungsten	1.50-2.00
Nickel	0.40 max
Vanadium	0.15-0.25
Niobium	0.04-0.09
Nitrogen	0.03-0.070
Aluminum*	0.02 max
Boron	0.001-0.006
Titanium	0.01 max
Zirconium	0.01 max

Table 1. Chemical Composition of P92/X10CrWVNb9-2

**EN10216-2 allows up to 0.04%Al*

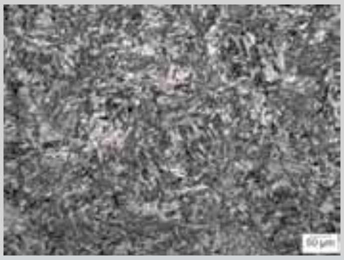


Figure 1. Typical P92 Microstructure

	8 [203] I.D.	11 [279] I.D.	14 [355] I.D.	17 [431] I.D.	20 [508] I.D.	23 [584] I.D.	26 [660] I.D.	29 [736] I.D.	32 [812] I.D.	35 [888] I.D.	38 [964] I.D.
1.0 [25]	45 [13.8]	45 [13.8]	45 [13.8]	45 [13.8]	42 [12.7]	42 [12.7]	40 [12.1]	34 [10.3]	30 [9.1]	25 [7.6]	26 [7.9]
1.5 [38]	45 [13.8]	45 [13.8]	43 [13.0]	33 [10.0]	37 [11.2]	32 [9.7]	31 [9.4]	30 [9.1]	24 [7.3]	25 [7.6]	23 [7.0]
2.0 [51]	45 [13.8]	40 [12.1]	33 [10.0]	34 [10.3]	30 [9.1]	29 [8.8]	30 [9.1]	23 [7.0]	25 [7.6]	22 [6.7]	17 [5.1]
2.5 [63]	40 [12.1]	32 [9.7]	33 [10.0]	27 [8.2]	28 [8.5]	27 [8.2]	23 [7.0]	18 [5.4]	21 [6.4]	18 [5.4]	
3.0 [76]	32 [9.7]	32 [9.7]	27 [8.2]	30 [9.1]	24 [7.3]	26 [7.9]	19 [5.8]	22 [6.7]	21 [6.4]	15 [4.5]	
3.5 [89]	27 [8.2]	27 [8.2]	25 [7.6]	26 [7.9]	22 [6.7]	29 [8.8]	20 [6.1]	19 [5.8]	16 [4.8]		
4.0 [101]	29 [8.8]	26 [7.9]	23 [7.0]	21 [6.4]	19 [5.8]	18 [5.4]	19 [5.8]	17 [5.1]	14 [4.2]		
4.5 [114]	25 [7.6]	24 [7.3]	22 [6.7]	19 [5.8]	17 [5.1]	18 [5.4]	17 [5.1]	16 [4.8]			

Possible Extruded Lengths Based on Wall Thickness and Inside Diameter
Lengths are shown in ft [m]

EXTRUSION

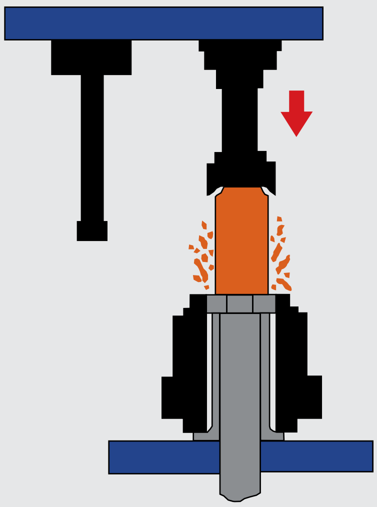
The Wyman Gordon Houston facility has a 14,000-ton blocking press and a 35,000-ton extrusion press.

The unique extrusion process is shown, schematically, on the following page. The process begins with a pre-heated ingot placed on the pedestal of the 14,000-ton blocking press. Downward pressure “upsets” the piece to remove scale and begins to mechanically “work” the material.

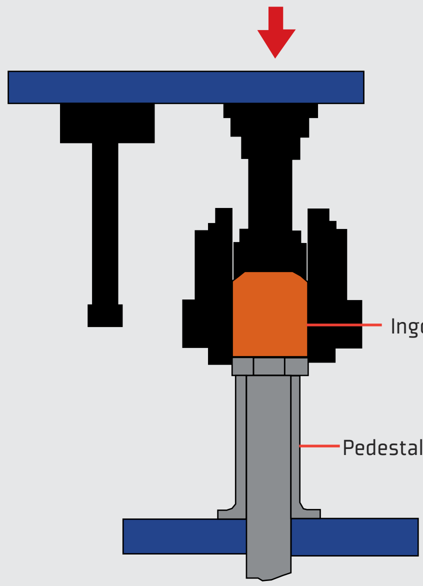
Next, the upper slide assembly applies pressure to “pot” the ingot. The ingot is then pierced with a punch, adding further “work” to the material. This is the first step in forming the inside diameter.

Using the 35,000-ton press, the mandrel is extended through the blocker to shape the final inside diameter. The extrusion is forged upward through the dies until the desired length is achieved .

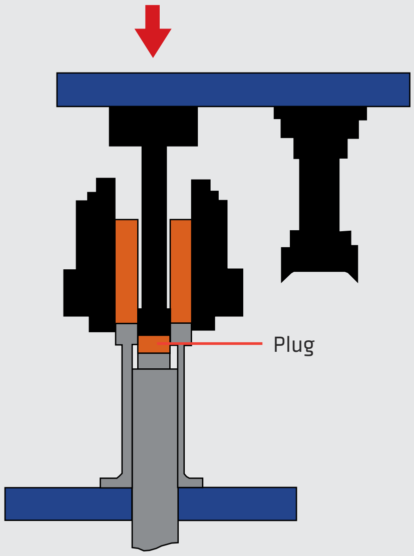
VERTICAL EXTRUSION PROCESS



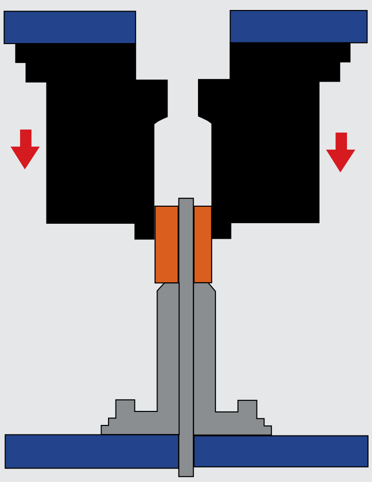
Upsetting Position to Remove Scale



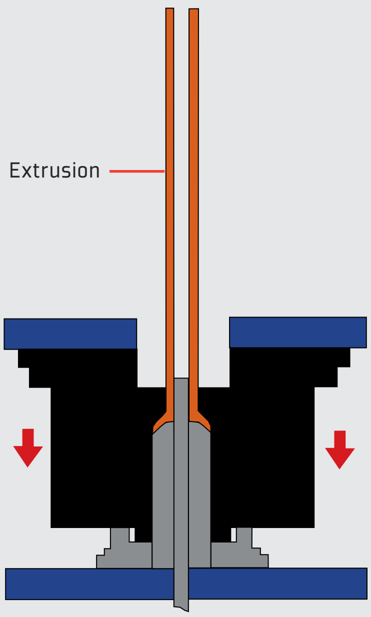
Potting Operation



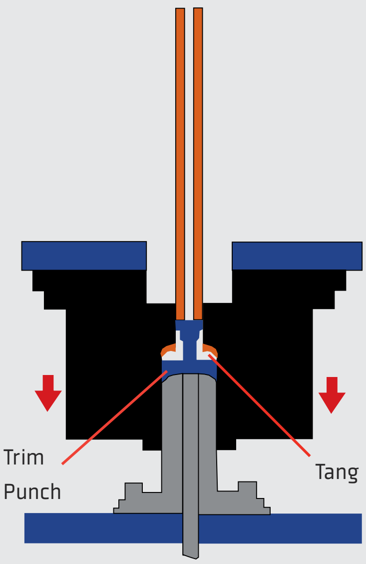
Piercing Position



Upper Bolster Begins to Move Down



Extrusion Fully Extended



Upper Bolster Moves Down to Trim Tang

TYPICAL ROOM TEMPERATURE TENSILE DATA

(Transverse Orientation)

UTS ksi [MPa]	YS ksi [Mpa]	% E	% RA
98 [676]	73 [503]	23	59.5
101 [696]	74 [510]	23.5	61.7
98 [676]	70 [483]	26.1	64.6
99 [683]	76 [524]	23.4	62.5
99 [683]	75 [517]	22.7	59.8
95 [655]	67 [462]	26.2	65.2
99 [683]	74 [510]	23.5	62
96 [662]	72 [496]	22.8	62.7

UTS ksi [MPa]	YS ksi [Mpa]	% E	% RA
98 [676]	74 [510]	23.8	57
100 [690]	76 [524]	24	64.5
99 [683]	74 [510]	23.4	63.5
101 [696]	76 [524]	25.3	67.2
102 [703]	76 [524]	26.2	67.7
99 [683]	73 [503]	24.7	66.3
101 [696]	76 [524]	26.2	63.5
101 [696]	77 [531]	23.2	61.2

TYPICAL ELEVATED TEMPERATURE TENSILE DATA

(Longitudinal Orientation)

TEST TEMPERATURE F [C]	UTS Ksi [MPa]	YS Ksi [MPa]	% E
600 [316]	80 [552]	60 [414]	22
600 [316]	76 [524]	60 [414]	22
600 [316]	78 [538]	58 [400]	22
600 [316]	79 [545]	58 [400]	23
600 [316]	81 [558]	64 [441]	22
800 [427]	74 [510]	52 [359]	21
800 [427]	72 [496]	57 [393]	21
800 [427]	72 [496]	54 [372]	22
800 [427]	74 [510]	54 [372]	22
800 [427]	74 [510]	56 [386]	21
1000 [538]	61 [421]	48 [331]	29
1000 [538]	59 [407]	46 [317]	30
1000 [538]	60 [414]	47 [324]	31
1000 [538]	60 [414]	49 [338]	29
1000 [538]	61 [421]	49 [338]	28

TEST TEMPERATURE F [C]	UTS Ksi [MPa]	YS Ksi [MPa]	% E
1050 [566]	56 [386]	43 [296]	32
1050 [566]	55 [379]	42 [290]	34
1050 [566]	55 [379]	43 [296]	38
1050 [566]	56 [386]	44 [303]	36
1050 [566]	57 [393]	47 [324]	36
1100 [593]	51 [352]	41 [283]	42
1100 [593]	50 [345]	41 [283]	33
1100 [593]	50 [345]	39 [269]	41
1100 [593]	50 [345]	40 [276]	39
1100 [593]	51 [352]	40 [276]	36
1150 [621	46 [317]	36 [248]	32
1150 [621	45 [310]	35 [241]	33
1150 [621	44 [303]	35 [241]	39
1150 [621	45 [310]	35 [241]	36
1150 [621	46 [317]	37 [255]	32

TYPICAL ROOM TEMPERATURE CHARPY V-NOTCH DATA

(Transverse Orientation)

3-SPECIMEN AVERAGE ft-lbs [J]	LATERAL EXPANSION 10^3 IN [MM]	% DUCTILE FRACTURE
64 [87]	43 [1.09]	70
62 [84]	45 [1.14]	95
84 [114]	59 [1.50]	95
55 [75]	39 [0.99]	90
66 [89]	44 [1.12]	80
65 [88]	43 [1.09]	95
79 [107]	48 [1.22]	95

3-SPECIMEN AVERAGE ft-lbs [J]	LATERAL EXPANSION 10^3 IN [MM]	% DUCTILE FRACTURE
71 [96]	49 [1.24]	95
76 [103]	51 [1.29]	90
54 [73]	43 [1.09]	95
67 [91]	40 [1.02]	90
87 [118]	50 [1.27]	70
56 [76]	42 [1.07]	90
93 [126]	60 [1.52]	90

FINISHING

P92 is supplied in the normalized and tempered condition. Specially designed carbottom furnaces provide computer-controlled, uniform heating. Precise permanent records for all heat treating cycles are maintained. Although not used for the processing of P92, quench tanks with heat exchangers and agitation systems are used for a wide variety of other products at WGFH. Following heat treatment, pipes are straightened and test rings are cut for mechanical and physical property data. The OD and ID grinding procedure removes any scale left on the pipe. Buffing is performed to leave the pipe surface finish at 275 RMS, or better, depending on customer requirements for ultrasonic examination or surface finish.

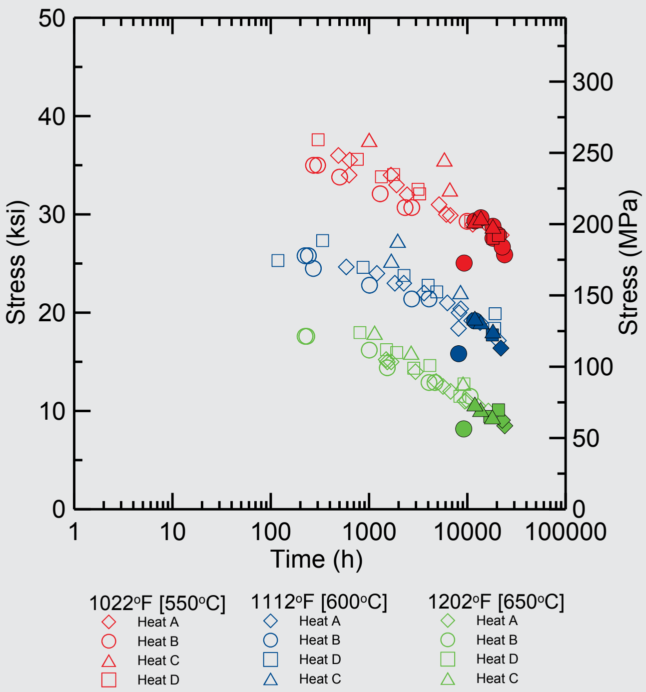
WELDING

P92 has good weldability. Welding can be performed by Shielded Metal Arc Weld (SMAW), Submerged Arc Weld (SAW), Gas Tungsten Arc Weld (GTAW), or Flux Cored Arc Weld (FCAW). Typically a combination of some or all of the following steps are used in the welding process for P92: preheat (on the order of 400 °F [200 °C]), interpass (typically around 600 °F [300 °C]), post-bake treatment (promotes hydrogen diffusion to prevent stress corrosion cracking), and post-weld heat treatment (PWHT). The weld performance is highly dependent on post weld heat treatment. Care must be taken to avoid heat treatment in the intercritical regime to avoid unwanted phase transformations, which can be detrimental to creep stability. This can be avoided by careful control of temperature and weld metal composition with respect to Ni and Mn content.

BENDING

P92 pipe is typically formed by hot bending rather than by cold bending. Careful control of temperature must be employed to prevent micro-cracking. A post-bending heat treatment consisting of normalize and temper cycles is usually required to ensure that there is no loss of creep strength during the bending process. Cold bending can be performed up to about 5%, without a post-bend heat treatment. Code specifications vary on the amount of allowable cold bending without heat treatment.

CREEP PROPERTIES



Note: Solid symbols indicate specimens which are still running.

The data here is representative of four different heats of P92, normalized and tempered. Creep tests were performed at three temperatures, 1022, 1112, and 1202 °F [550, 600, and 650 °C].

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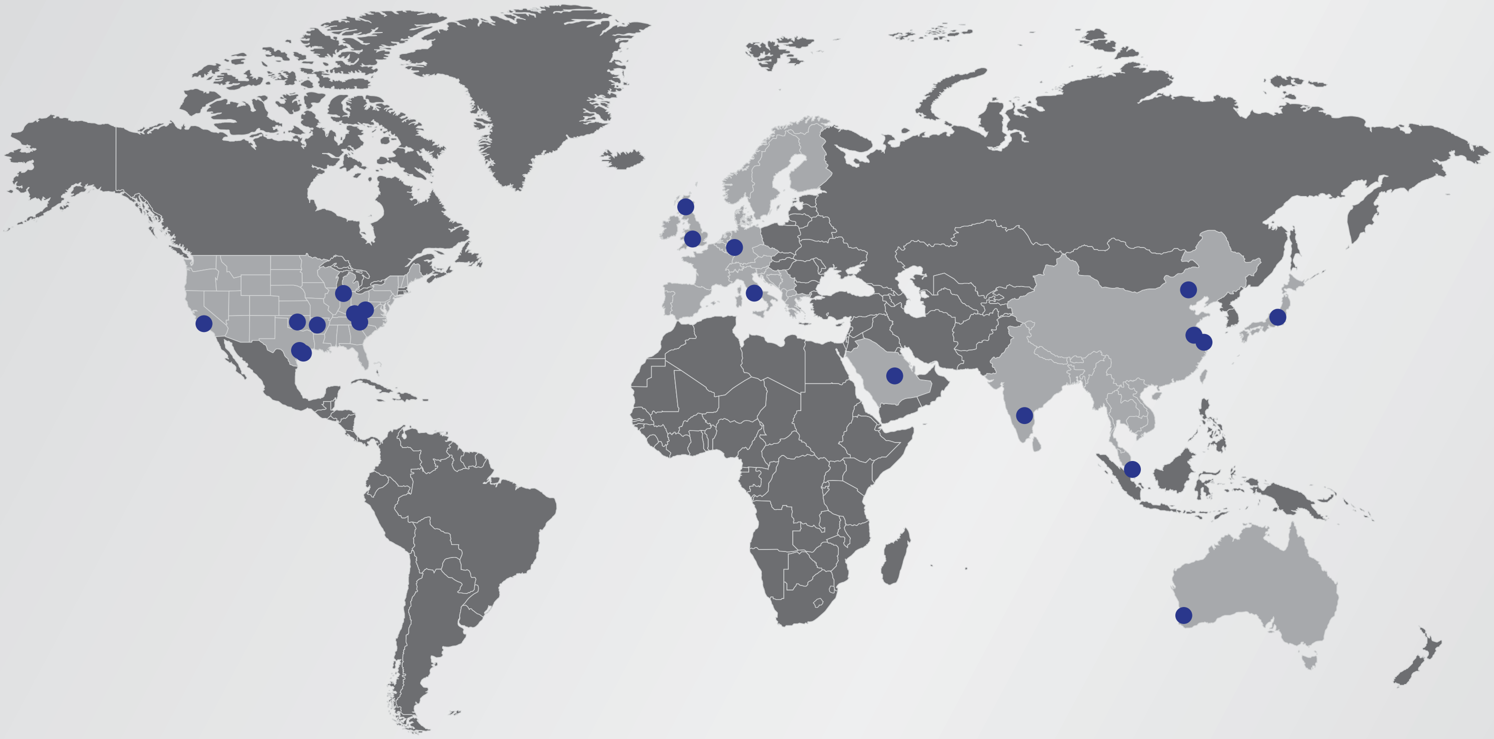

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