

Comparative Analysis of Chemical Composition Between our X60 PSL2 SSAW Pipe and API 5L X60 PSL2 Standard

1. Comparison Table Between Chemical Composition of Our SSAW Pipes and API 5L X60 PSL2 Standard Requirements

Table1 Comparison Table of Chemical Composition

化学成分 Chemical Composition (%)

No.	Grade	碳	锰	磷	硫	钒	钛	铌	钒+铌+钛	碳当量	铜	硼	铬	硅	镍	钼
		C	Mn	P	S	V	Ti	Nb	V+Nb+Ti	CE(IIW)	Cu	B	Cr	Si	Ni	Mo
API 5L PSL2 (Maximum)	X60	0.22	1.40	0.025	0.015	0.10	0.04	0.05	0.15	0.43						
Our MTC	X60	0.14-0.16	1.40	0.013	0.004-0.006	0.060	0.008	0.007	0.075	0.410	0.020	0.0002	0.080	0.33	0.020	0.020
Comparison Result		Conforms	Conforms	Conforms	Conforms	Conforms	Conforms	Conforms	Conforms	Conforms						

As can be seen from the above table, the chemical composition of the X60 SSAW pipes produced by our factory fully complies with the requirements of the API 5L X60 PSL2 standard.

2. Effects of Element Contents on Steel Pipe Properties

2.1 Effect of Carbon(C) Content on Material Properties

Property	Impact of High Carbon Content	Impact of Low Carbon Content (Modern Direction)
Strength	The most direct and cost-effective element for increasing strength . However, PSL2 X60 has an upper strength limit; higher carbon is not necessarily better.	Strength is compensated for through microalloying (Nb, V, Ti) and TMCP processes to meet the X60 requirement.
Weldability	Severely deteriorates . Carbon is the main factor increasing the Carbon Equivalent (CEV/Pcm) , leading to hardening in the weld heat-affected zone and a sharp increase in cold crack susceptibility.	Significantly improves . Low carbon equivalent means a wider welding procedure window, lower preheat requirements, and higher safety and reliability of welded joints.
Toughness	Reduces toughness . Carbon increases the steel's brittleness tendency, particularly reducing low-temperature impact toughness.	Greatly enhances . Low carbon content is the foundation for achieving good low-temperature toughness, especially suitable for pipelines in cold regions.
Formability & Workability	Poor plasticity; prone to cracking during cold bending, expansion, and other processing operations.	Better plasticity and ductility, more suitable for field construction and complex forming.
Corrosion Resistance	Can have adverse effects in certain corrosive environments (e.g., H ₂ S stress corrosion).	Generally has a positive effect on corrosion resistance.

Summary

For API 5L PSL2 X60:

Higher carbon content is absolutely not better; high carbon harms weldability, toughness, and safety.

Provided the minimum yield strength (415 MPa) is met, lower carbon content generally indicates better overall material properties (weldability, toughness, workability) and higher manufacturing technology.

When selecting materials, it's important not only to check if the carbon content "meets the standard maximum" but also to pay attention to whether its actual carbon content and carbon equivalent are sufficiently low. This directly affects the construction difficulty, cost, and long-term operational safety of the pipeline.

Therefore, the answer is clear: Under the constraint of achieving X60 strength, lower carbon content is better.

Core Conclusion

The fundamental philosophy of modern high-performance pipeline steel (such as PSL2 X60) is: To pursue the lowest possible carbon content while ensuring the specified strength is achieved.

2.2 Effect of Manganese(Mn) Content on Material Properties

Property	Effects of Moderately High Manganese Content	Effects of Excessively Low Manganese Content
Strength	Significantly increases strength. Manganese is an effective solid solution strengthener that economically improves yield and tensile strength, helping to meet the X60 strength requirement.	May lead to insufficient strength, requiring more carbon or other costly microalloying elements for compensation, thereby increasing cost.
Toughness	Can improve toughness under low-carbon conditions. Manganese refines ferrite grains and lowers the ductile-to-brittle transition temperature. However, excessively high content (especially when carbon is also high) increases segregation and banded structure risks, which can impair toughness and isotropy	Limited improvement in toughness; may not favor good low-temperature toughness.
Weldability	Dual effects: 1. Positive: Partially substitutes for carbon, lowering the carbon equivalent and improving weldability. 2. Risk: Excessively high content increases hardening tendency and cold crack susceptibility in the weld heat-affected zone (especially when combined with carbon) and may promote centerline	Reduces the risk of welding cold cracks but may require adjustments to welding materials due to insufficient strength.

	segregation, leading to lamellar tearing.	
Processability	Improves hardenability, aiding in the formation of fine bainitic microstructure during TMCP processes. However, excessive amounts increase centerline segregation in continuous cast slabs and banded structures after rolling, deteriorating through-thickness (Z-direction) properties.	Lower hardenability, limited contribution to transformation strengthening in TMCP processes.
Corrosion Resistance	Has a slight positive effect on improving atmospheric corrosion resistance.	Negligible impact.

Summary

For API 5L PSL2 X60:

Manganese content is not better when higher or lower; it should be an optimized value that matches carbon content, microalloy design, and production processes.

A typical advanced X60 steel composition design is: low carbon (~0.07%) + medium-high manganese (~1.50%) + microalloying (Nb, V, etc.). This combination optimally balances strength, toughness, weldability, and cost-effectiveness.

When selecting materials, pay attention to the reported actual manganese content and evaluate it comprehensively alongside carbon content and carbon equivalent (CEV/Pcm). A reasonable manganese content (e.g., 1.40%-1.60%) indicates good design. Simply pursuing "high manganese" or "low manganese" is unscientific.

Therefore, the answer lies in "optimization" rather than "extremes." Manganese is a "modulator" rather than the "main driver" of pipeline steel performance, and its content must be precisely positioned within the overall alloy design.

Core Conclusion

Manganese is an important and beneficial alloying element, but its content must be controlled below the maximum limit specified in the standard. The ideal scenario is to maintain it within a "sweet spot" where its advantageous effects are maximized while its disadvantages are minimized (e.g., 1.40%-1.60%, depending on the process), rather than pursuing extremely high or low levels.

2.3 Effect of Phosphorus(P) Content on Material Properties

Unlike carbon—which can contribute to strength within a certain range—phosphorus is an element that is almost "**all harmful and no benefit**" in steel and must be strictly limited.

Property	Harm of High Phosphorus Content	Benefit of Low Phosphorus Content
Low-Temperature Toughness	Severely deteriorates. Phosphorus is an extremely strong solid solution strengthening element that sharply raises the ductile-to-brittle transition temperature, making the material highly prone to brittle fracture at low temperatures. This is the most critical hazard of phosphorus.	Significantly improves low-temperature toughness, ensuring pipeline safety in cold regions.
Temper Embrittlement	Markedly increases. Phosphorus segregation at grain boundaries can cause embrittlement in alloy steels (especially Cr-Mo steels) after tempering. Although pipeline steels do not undergo high-temperature tempering, this principle illustrates the grain boundary hazards of phosphorus.	Avoids grain boundary embrittlement, resulting in a more stable microstructure.
Weldability	Damages. Phosphorus increases the tendency for grain boundary segregation and liquation cracking in the weld heat-affected zone, raising the risk of embrittlement in welded joints.	Improves the toughness and reliability of welded joints.
Formability	Reduces plasticity. The solid solution strengthening effect of phosphorus decreases the ductility of steel, which is unfavorable for cold working (e.g., pipe bending, flaring).	Enhances the plastic workability of the material.
Corrosion Resistance	May improve general atmospheric corrosion resistance (in combination with copper), but can be detrimental in acidic environments (e.g., H₂ S).	Reduces the risk of localized corrosion caused by segregation.

How Does API 5L PSL2 Regulate This?

The standard specifies phosphorus content with an extremely strict "**Maximum**" limit.

For PSL2 Grade X60, the typical maximum for phosphorus is: $\leq 0.025\%$ or $\leq 0.020\%$ (depending on thickness and customer agreement).

This is much lower than the requirements for ordinary structural steels. "**Meeting the standard**" is not the same as "**excellent**." Actual advanced levels typically require $\leq 0.015\%$ or even $\leq 0.010\%$.

Summary

For API 5L PSL2 X60:

Phosphorus content must be as low as possible—no debate.

High phosphorus content catastrophically damages the low-temperature toughness of the material and increases the risks of welding issues and brittle fracture, posing a serious threat to pipeline safety.

When selecting materials, phosphorus content is a key indicator of the steel mill's capability to produce clean steel and of the material's safety grade. An extremely low phosphorus content value is an essential "identity card" for high-performance pipeline steel.

Therefore, the answer is unequivocal: Phosphorus content must be extremely low, and the lower, the better. This is the lifeline for ensuring pipeline safety, especially in low-temperature environments.

Core Conclusion

Phosphorus content must be controlled well below the extremely low maximum limit specified in the standard, and in practice, "the lower, the better" should be pursued.

2.4 Effect of Sulfur(S) Content on Material Properties

In API 5L PSL2 Grade X60, sulfur, like phosphorus, is a harmful element that must be strictly controlled, and its content must be kept as low as possible.

Property	Harm of High Sulfur Content	Benefit of Low Sulfur Content
Toughness (especially transverse and through-thickness)	Severely deteriorates. Sulfur combines with manganese to form MnS inclusions , which appear as elongated or spindle-shaped distributions along the rolling direction. These plastic inclusions act as stress concentrators and crack initiation sites, significantly reducing transverse impact toughness and reduction of area (Z-direction properties) , greatly increasing the risk of lamellar tearing .	Significantly improves anisotropic toughness , ensuring reliable fracture resistance in all directions.
Formability and Workability	Severely impaired. Welding heat can cause sulfide aggregation at grain boundaries, dramatically increasing susceptibility to welding hot cracking (solidification cracking) . Sulfide inclusions also act as initiation points for hydrogen-induced cracking.	Significantly reduces the tendency for welding hot and cold cracks, improving weld joint quality and safety.
Corrosion Resistance (especially in H₂ S environments)	Catastrophic impact. Sulfides are a major cause of Hydrogen-Induced Cracking (HIC) and Sulfide Stress Corrosion Cracking (SSCC) . In wet H ₂ S environments, sulfide inclusions act as hydrogen traps, promoting hydrogen accumulation and crack formation.	A mandatory prerequisite for pipeline steels used in sour service environments . Ultra-low sulfur is a core requirement for HIC-resistant steel.
Fatigue Performance	Reduced. Sulfide inclusions act as fatigue crack initiation sites, significantly shortening the material's fatigue life.	Improves fatigue resistance and extends component service life.

Summary

For API 5L PSL2 X60:

Sulfur content must be as low as possible—no debate. It is a "negative element" that must be minimized.

High sulfur content comprehensively and systematically impairs mechanical properties, process performance, and service safety, making it a major risk factor for catastrophic failures in pipelines, especially in sour service pipelines.

Sulfur content is a "dividing line" between ordinary steel and high-performance clean steel. During procurement: Clearly specify internal control sulfur requirements that are far stricter than the standard upper limits.

Therefore, the answer is unequivocal: Sulfur content must be at an "ultra-low" level, and the lower, the better. This is the foundation for ensuring pipeline integrity, preventing localized failures, and withstanding demanding service conditions.

Core Conclusion

Sulfur is an extremely detrimental impurity in steel, and modern high-performance pipeline steels require it to be at an "ultra-low sulfur" level. Sulfur content must be well below the maximum limit specified by the standard, and "the lower, the better" is pursued in production—this is a key indicator of a steel mill's capability to produce clean steel.

2.5 Effect of V+Nb+Ti Total Content on Material Properties

In API 5L PSL2 Grade X60, the total content of vanadium (V), niobium (Nb), and titanium (Ti), as the core microalloying combination, is not better when higher. Instead, it must follow the principle of "fine proportioning and synergistic optimization."

Performance Aspect	Synergistic Benefits with Optimized Proportions and Processing	Risks of Excessively High Total Content or Imbalanced Proportions
Strength Contribution Mechanism	<ul style="list-style-type: none"> • Niobium (Nb): Dominates grain refinement (recrystallization inhibition) and low-temperature precipitation strengthening. • Vanadium (V): Dominates medium-to-high temperature precipitation strengthening (V(C,N)). • Titanium (Ti): Fixes nitrogen and refines grains, secondarily improving weldability. <p>Together, they enable the dual mechanism of "grain refinement + precipitation strengthening" at low carbon levels, efficiently achieving X60 strength.</p>	<ul style="list-style-type: none"> • Diminishing Returns: Oversaturation and coarsening of precipitates reduce strengthening efficiency. • Significant Cost Increase: Microalloying elements are expensive; excessive addition is uneconomical. • Narrower Process Window: Sensitivity to rolling and cooling processes increases sharply, making production control difficult.
Toughness and Weldability	<ul style="list-style-type: none"> • Low Carbon Prerequisite: Microalloying is the foundation for achieving "high strength + high toughness." • Contribution of Ti: TiN inhibits grain growth in the weld coarse-grained heat-affected zone (HAZ), significantly improving HAZ toughness. • Benefit of Fine Grains: Niobium-dominated grain refinement is the most effective means to enhance toughness. 	<ul style="list-style-type: none"> • Toughness Deterioration: Excessive or coarse carbonitrides act as crack initiation sites, severely impairing impact toughness, especially at low temperatures. • Weldability Risks: Excessive microalloying elements may increase susceptibility to reheat cracking in the weld HAZ (particularly in thick-walled pipes). • Anisotropy: Excessive addition may intensify banded structures, leading to directional property differences.
Process Compatibility	Reasonable total content makes the material responsive to TMCP (Thermo-Mechanically Controlled Processing) , facilitating the attainment of desired microstructures.	Excessively high total content demands stricter rolling and cooling schedules; otherwise, undissolved phases or abnormal microstructures may occur, increasing production scrap rates.

Cost-Effectiveness	Achieving performance targets at the lowest total alloy cost reflects advanced metallurgical design.	Significantly increases raw material costs, representing "over-alloying" with poor techno-economic efficiency.
---------------------------	------------------------------------------------------------------------------------------------------	----------------------------------------------------------------------------------------------------------------

Summary

The total V+Nb+Ti content should be minimized while achieving performance targets. Its core value lies in "synergistic effects" and "precise matching," not "quantity accumulation." Exceptional X60 steel is the product of metallurgical intelligence, not a simple aggregation of expensive elements.

Core Conclusion

Microalloying aims for a "1+1+1 > 3" synergistic effect, not simple content accumulation. The total content of these three elements has an economical and effective window that matches the strength target and processing route (for X60 grade, the typical total content range is approximately 0.07% - 0.15%). Blindly increasing the total content only leads to higher costs, diminishing returns, and potential impairment of material properties.

2.6 Effect of Carbon Equivalent(CE IIW) on Material Properties

In API 5L PSL2 Grade X60, the carbon equivalent (CE IIW) is the core indicator for assessing material weldability and cold cracking risk, and a lower value is unequivocally better.

Performance Aspect	Risks of High Carbon Equivalent	Risks of High Carbon Equivalent
Weldability – Core Impact	<p>Cold cracking risk increases sharply: For every 0.05% increase in CE, the required preheat temperature may need to rise by approximately 50°C.</p> <ul style="list-style-type: none"> • High hardening tendency: Promotes formation of hard and brittle martensite in the weld heat-affected zone (HAZ). • Diffusible hydrogen accumulation: Increases susceptibility to hydrogen-induced cracking (HIC). • Narrow process window: Highly sensitive to welding parameters (heat input, interpass temperature), resulting in low tolerance for field construction errors. 	<p>Excellent weldability:</p> <ul style="list-style-type: none"> • Very low cold cracking risk: Welding possible at lower or no preheat temperatures. • Controlled HAZ soft zone: Microstructure primarily consists of tougher bainite/acicular ferrite. • Wide process window: Suitable for automation and high heat input welding, improving construction efficiency and quality consistency.
Heat-Affected Zone (HAZ) Toughness	<p>Severely degraded: Coarse martensite and high-carbon twinned martensite cause a drastic drop in HAZ impact toughness, creating a weak point in the pipeline.</p>	<p>Well maintained: Fine bainitic microstructure allows HAZ toughness to approach or even match base metal levels, ensuring overall joint toughness.</p>
Field Construction Adaptability	<p>Very poor:</p> <ul style="list-style-type: none"> • Requires complex preheat and postheat procedures under harsh conditions (low temperature, high humidity). • Very high risk during repair and rework welding. • Increases construction costs and extends schedules. 	<p>Excellent:</p> <ul style="list-style-type: none"> • Adaptable to construction in severe weather conditions. • Simplifies welding procedures, reduces absolute dependency on welder skill. • Significantly lowers comprehensive construction costs and schedule risks.
Long-Term Service Safety	<p>Increased risk: High hardness and residual stress in the HAZ can initiate stress corrosion cracking (SCC) or fatigue cracks.</p>	<p>High safety margin: Uniform mechanical properties and low residual stress enhance overall pipeline failure resistance.</p>

Summary

For API 5L PSL2 X60:

Carbon Equivalent (CE IIW) is the gold standard for measuring material "weldability-friendliness" and "construction safety," and it must be as low as possible.

A high CE value represents technological regression and a major engineering risk, indicating that the material is extremely sensitive to welding procedures and highly prone to hard-to-detect delayed cracking during field construction.

Carbon Equivalent (CE IIW) is the "weldability lifeline" of pipeline steel. Its level directly determines the success and long-term safety of pipeline construction. Pursuing the lowest possible carbon equivalent is an unwavering technical principle for modern high-performance pipeline steel.

Core Conclusion

The carbon equivalent must be strictly controlled below the maximum limit specified by the standard or project specifications, and "as low as reasonably achievable" should be pursued in actual production. For X60 PSL2, modern technology can consistently maintain CE values at $\leq 0.43\%$ or even lower, representing excellent welding safety and process tolerance.