

## New Metallurgy Improves Performance

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MAYFIELD HEIGHTS, OH.—Equipment is only as good as the material from which it is made. This holds true in all industries, but any petroleum or drilling engineer can attest that it is especially so

in the oil and gas sector, where equipment often is deployed in extreme and varied operating environments, and is pushed to the limits of endurance.

Base materials matter, whether dealing with the high torque and friction conditions of extended-reach horizontal drilling, the pressure and temperature extremes of

deepwater projects, or the degrading effects of corrosion in production operations. Conventional alloys remain the backbone of the oil and gas industry, but materials engineers and equipment designers recognize significant shortcomings in the traditional materials used to construct drilling, completion and production tools, as well as permanent downhole and even surface equipment, in certain applications.

In direct response to the need for materials capable of withstanding the ever-increasing demands inherent in engineering and installing a wellbore, legacy copper-nickel-tin alloy (UNS C72900) has been re-engineered with next-generation metallurgical capabilities to meet the demands of even the most challenging field applications. The enhanced C72900 materials enable engineers and designers to build tools that have added capability and improved reliability, and provide more cost-saving opportunities than previously were possible without having to resort to exotic and expensive specialty alloy products.

The properties of the high-strength, spinodally-hardened copper-nickel-tin alloys provide many advantages in demanding end-use applications. These alloys are lead- and beryllium-free, and demonstrate excellent corrosion and corrosion-related stress cracking resistance in seawater, chlorides and sulfides.

### Enhanced Properties

C72900 alloys always have been preferred because of their excellent nongalling behavior. However, use of traditional C72900 tempers has been limited in the past by the one mechanical characteristic—fracture toughness—that made them inadequate for components subject to

TABLE 1

Mechanical Properties of New C72900 Tempers versus Legacy C72900			
	Yield strength (ksi)	Elongation (%)	Typical average Charpy V-notch energy (foot-pounds)
Improved C72900 (version 1)	95	18	40
Improved C72900 (version 2)	110	15	30
Legacy C72900	110-150	3-10	6

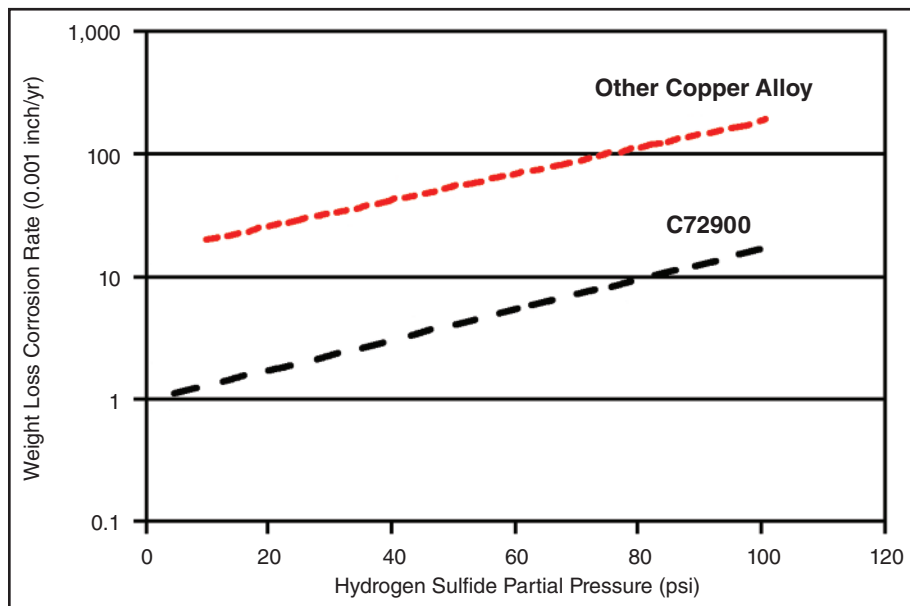


The new copper-nickel-tin alloy tempers achieve good longitudinal and transverse properties at larger diameters, and they can be manufactured as hollow bars directly off the mill, offering significant cost savings by eliminating the need to machine the core from a solid bar.



**FIGURE 1**

**Weight Loss Corrosion of New C72900 versus Other Copper Alloy in Sour Service**



shock loading. To address this, the existing copper-nickel-tin alloy was re-engineered to produce a unique material that delivers a dramatic increase in fracture toughness without sacrificing its high strength.

Table 1 shows the key mechanical properties of yield strength, elongation, and Charpy V-notch for two versions of the new tempers compared with legacy C72900. The Charpy V-notch impact test determines the amount of energy absorbed by a material, and is the standard measure of “toughness” (i.e., ductility/brittleness).

There are many benefits to using the improved copper alloy system in the drilling environment. First, the material is not magnetic, which is a particularly important feature since magnetic interference in a horizontal or directional drilling operation impacts the precision with which a wellbore can be located. In fact, there are no steels available that display the level of nonmagnetism these materials exhibit.

In addition, corrosion resistance as a copper alloy system is outstanding in drilling applications. The steels that may be commonly used for some of the applications envisioned for copper alloys are highly susceptible to chloride stress corrosion, cracking and pitting, which in many cases cause the components to be taken out of service to avoid failure. The new C72900 tempers resist that type of damage.

In developing the new tempers, fracture

toughness was increased so much that the erosion resistance became much better than that of legacy C72900 versions. The high speed and fast flow rates of drilling mud and rock cuttings can erode metals. Increased fracture toughness, therefore, is an enhancement that increases the longevity of manufactured components.

Furthermore, techniques to apply tenacious hard coatings using high-velocity

oxy fuel flame methods often are used effectively to enhance erosion resistance of C72900 components in the most extreme flow regimes.

Occasionally, in balanced or slightly underbalanced drilling operations, production fluids can make their way into the drilling tool environment. To counter this eventuality, the enhanced copper-nickel-tin alloy has a corrosion rate in sour service more than two orders of magnitude less than the typical legacy copper-based material, providing significant benefits in such situations (Figure 1).

### Improved flexibility

While providing improved fracture toughness and corrosion resistance properties, C72900 material also possesses a high degree of ductility in an alloy system that has an elastic modulus that is 50 percent less than steel. This means the component can bend twice as much without suffering permanent deformation, and tools can be built that can drill wellbores with a much sharper radius. This allows greater flexibility in building the wellbore, and is a significant benefit in drilling deep, long-lateral horizontal wells.

The radius that can be deployed, and drilling from the vertical section to the horizontal leg, is much sharper than what could be achieved in the past. Essentially, the new alloy means that the horizontal wellbore can be placed into the pay zone



**In response to the ever-increasing demands inherent in today's field applications, legacy C72900 alloy has been re-engineered with next-generation capabilities to give engineers and designers new capabilities while also providing cost-saving opportunities. The new tempers provide increased fracture toughness without sacrificing strength.**



more quickly than previously was possible.

The new copper-nickel-tin alloy also has been utilized for high-pressure/high-temperature electrical and electronic connectors for signal and power transmission. These are small pins and sleeves for connecting electronic circuits that maintain their contact force in the connection, including at high temperatures, where other materials tend to soften, losing the integrity of the connection continuity.

In these applications, the new alloy actually will get stronger and maintain the contact force even better over time. The material is unique in that it has better retention of strength at elevated temperature than any other metal system in this environment.

The new alloys also can be applied in thin-walled precision tubing for downhole instrumentation housings and battery housings, where it offers high strength, nonmagnetic properties and very good stress relaxation properties. As the temperature of the drilling environment increases, it tends to cause metals to lose their strength and capacity to operate at high temperatures and pressures. Conversely, the alloys do not lose strength, even in temperatures higher than 350 degrees Celsius.

## Filling The Gap

Several service companies are validating the suitability of the new copper-nickel-tin alloy for filling a “performance gap” for more permanent equipment.

Steel tubulars made with 13 percent chromium (13-Cr) steel can be used reliably up to 150 degrees C and 1.5 percent hydrogen sulfide partial pressure, but beyond those conditions, the next step is to use a nickel-based alloy, which is expensive and difficult to machine.

The C72900 alloy machines faster than even free-cutting steel, with less tool wear, meaning the components cost less. Typically, other types of metal need to be machined into their primary mill form geometries (such as a hollow bar), which is a process that can prove to be more expensive than the material itself.

However, there are data that indicate the performance gap can be filled with a material such as the enhanced C72900. Although not generally suitable for HP/HT installations, using C72900 in the 90 percent of applications that are mildly to moderately sour is worthy of further study. Where 13-Cr steel cannot be used, and it is not technically necessary to use a nickel-based alloy, it is possible that C72900 tempers may prove adequate performance-wise and at lower component cost.

More permanent applications for C72900 are being considered now that these tempers are being manufactured with adequate toughness and ductility at the required strength levels.

One example of applications in downhole drilling and logging tools is Houston-based Compass Directional Guidance Inc., which is using 1 $\frac{3}{8}$ -inch outside diameter tubes of the copper-nickel-tin alloy to build slim-hole measurement-

while-drilling tools for ultradeep wells. The slim-hole tools have pressure tolerances up to 25,000 psi and can be run with 2 $\frac{1}{2}$ -inch OD mud motors and collars, rather than the more typical 20,000-psi, 3 $\frac{1}{2}$ -inch MWD tools.

The 1 $\frac{3}{8}$ -inch tubes are utilized to make all the housings containing the sensitive electronics and sensors of the slim-hole MWD tools. A number of challenging drilling environments are suitable for this technology, but one application is the Terim oil field in Northwest China, where Compass Directional Guidance’s systems are being run in wells more than 22,000 feet deep.

A9 Manufacturing is a precision machining shop that fabricates downhole tools, including Compass Directional Guidance’s 1.375-inch slim-hole MWD system. After having issues with the pressure barrel’s high-temperature performance requirements when produced from copper beryllium (CuBe), A9 and Compass decided to try one of the copper-nickel-tin alloy tempers. It was easy to machine, and after running the slim-hole MWD system down hole, its resistance to erosion and stress cracking proved superior to high-temperature CuBe while maintaining similar resistance to galled connections (the industry traditionally has relied on CuBe for resistance to galled connections).

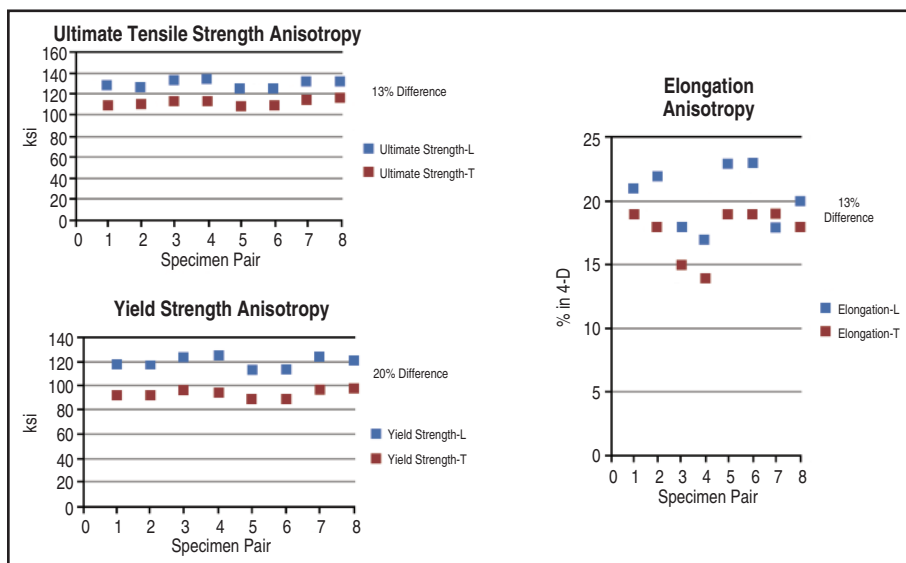
## Larger-Diameter Capability

In the metals industry, it is always challenging to achieve good properties—both longitudinal and transverse—all the way across the diameter of a piece of metal that is, for example, seven inches in diameter, as well as across its entire length. Some of the components that are being constructed from the new tempers are significantly larger in diameter. Anisotropy of mechanical properties is typical in large section bars.

Anisotropy is a material’s directional dependence to mechanical properties. For example, wood is naturally anisotropic because its strength, hardness and other properties differ when measured in different orientations (with or against the grain). Fortunately, as shown in Figure 2, this phenomenon is both minimal and consistent in the new C72900 tempers.

The tempers may be manufactured as hollow bars directly off the mill, eliminating the need to machine the core from a solid bar, which offers significant cost savings. Alternative materials typically

**FIGURE 2**  
Typical Anisotropy of New C72900 Tempers







come from the mill as a solid bar, and must be trepanned or gun-drilled in order to convert them into a hollow bar (the form taken by most large-diameter components), which is very expensive and wasteful.

The industry continues to demand high-strength, corrosion-resistant materials that are not susceptible to hydrogen embrittlement. The C72900 tempers are a prime example of how materials engineers are developing new alloys that can be economically mass produced to meet the industry's demands.

Expert engineers and scientists in metallurgy and materials are continually pushing the boundaries of advanced material solutions. The keys to future technology development are for material engineers to remain "tuned in" to what the industry is searching for, invest in dedicated research and development programs, and conduct experiments in production facilities, since tests conducted in the laboratory often do not translate to events that can occur in real life.

In today's economic environment, it is not only technical challenges that operators are trying to solve. It is certainly a different world now, and providing economic savings is crucial. Service companies and operating companies alike still need optimal performance, but they also need the total cost of ownership of an asset to be as low as possible without sacrificing performance. Many times, design changes

alone will not achieve both requirements. Materials engineering changes are needed as well, and often are the most important part of the solution.

Questions need to be asked, such as what a particular piece of equipment will be made of. In what form will the needed material be delivered? How much is it going to cost to turn the metal into a component to go into the equipment?

The copper-nickel-tin alloy tempers are a result of materials engineering firms engaging in these dialogues with strategic partners in the oil and gas industry, and investing and innovating to perfect the processes necessary to create and improve the tempers, and then systematically gathering the data to prove their properties can be relied on in real-world applications. □



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