Advanced Alloys
Alloy Selection for the Oil and Gas Industry

Abstract

With oil prices only starting to recover from the sharp decline of late 2008, the oil and gas industry faces a trying time. The combination of reduced revenue with increased environmental focus and regulations mean that the industry faces increasing costs while needing to minimize overhead in order to keep operations profitable.

The oil and gas industry operates in harsh environments; materials that are considered tough and corrosion resistant in any other industry can find themselves failing rapidly when subjected to the operating conditions of the oil and gas industry. Every time a tool or component fails, it necessitates repair or replacement, potentially necessitating the partial or complete shutdown of an operation. The direct cost of the repair can quickly pale in comparison the the cost of a work stoppage.

The industry needs materials that have excellent impact toughness, phenomenal corrosion resistance and superb fatigue properties. Beryllium copper (BeCu) alloys address these needs in a cost effective and efficient manner that traditional materials, like stainless steel, fail to.

1 Introduction

Corrosion is a fact of life in the oil and gas industry but is a particular problem when dealing with sour gas. The presence of hydrogen sulfide – H_2S in sour gas results in well documented stress corrosion cracking which leads to the premature failure of equipment under loading conditions that would normally be considered safe. When combined with corrosion due to the presence of acidic compounds and the like, the result is that equipment sees dramatically shorter lifespans than in almost any other industry.

Beyond merely the environmental factors surrounding corrosion, the severe loading conditions equipment is subjected to must be considered. Equipment needs to be able to withstand near continuous use while being subjected to large impact loads, necessitating not only excellent strength, but also fracture toughness and fatigue resistance.

In addition to these already significant concerns, magnetic and sparking properties also need to be considered for certain applications. When working in a combustible environment, as is often the case for the oil and gas industry, tools need to be non-sparking. Traditional tool making materials, such as tool steels can emit sparks which can lead to catastrophic results. Similarly, steel alloys are not suitable for many instrument housings due to their magnetic properties. These are both applications where beryllium copper alloys possess the properties needed to meet the challenges posed by the work environments faced by the oil and gas industry.

2 Corrosion Management

Corrosion presents possibly the greatest strategical issue for the oil and gas industry. Repairing or replacing corroded production line equipment necessitates shut downs, and the cost in terms of lost production is far worse than the cost of maintenance or even the part itself.

According to a study funded by the United States Federal Highway Administration and conducted by CC Laboratories, the cost of corrosion to the oil and

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Table 1: The cost of corrosion to the oil and gas industry [1]

Sector	**Cost (Millions)**
Surface piping and facility costs	$589
Downhole tubing expenses	$463
Corrosion related capital expenditures	$320
Total	$1372

gas industry in 1998 exceeded $1.3 Billion (broken down in Table 1) for the exploration and production sector, and the cost to the gas distribution industry was a further $5 Billion [1].

The corrosive environment that equipment must operate in is due to one or both of two factors. First is the naturally occurring corrosive elements, such as hydrogen sulfide that are simply a fact of life when dealing with wells. The second is corrosive elements which are intentionally added to the environment, such as hydrofluoric or hydrochloric acids when acidizing a well.

Steel is highly susceptible to both stress corrosion cracking as well as corrosion due to the acidic environment [2]. While austinitic stainless steels are generally considered corrosion resistant and are indeed better capable of surviving acidic, abrasive environments, they are too highly prone to stress corrosion cracking in the presence of hydrogen sulfide. Because of their improved performance in the acidic environments, austinitic stainless steels are indeed strategically used in drill strings. However, capillary action can draw acid into the threads and subsequent corrosion of the mating surface makes disassembly impossible.

BeCu alloys such as C17200 on the other hand are highly resistant to stress corrosion cracking. Alloys such as C17200 maintain their mechanical properties, even in sour gas environments. Furthermore, they have good resistance to corrosion in the presence of dilute hydrochloric and hydrofluoric acids.

Because of this resistance to corrosion and stress corrosion cracking, beryllium copper alloys can be used to minimize downtime and maintenance costs. A common example is the use of BeCu alloy coupling sleeves. These sleeves facilitate disassembly of the drill string by eliminating the steel-steel mating surface preventing their fouling by corrosion. Leveraging these same properties, BeCu alloy valve gates and seats allow consistent valve performance, even in sour gas applications. A similar steel product would corrode, resulting in poor valve actuation and potentially leaks or total failure.

3 Response of BeCu Alloys to Severe Loadings

The corrosion resistance of BeCu alloys are meaningless if the alloys do not have the strength and toughness to survive the types of loadings they will experience during usage. During a drilling operation, running into a tough strata can cause severe load fluctuations as the bit slows or stalls and then accelerates as torque is added. These dynamic loading conditions necessitate equipment having excellent strength and toughness.

This is another area where BeCu alloys excel. They are the strongest of all copper alloys and possess hardness, yield and fatigue strengths similar to those of steel alloys. These are crucial properties to have when these materials are used in components for downhole equipment, they must not only survive the corrosive environment, but also large impact and cyclic loads as well significant abrasion. BeCu alloys such as C17200 can be provided in a wide range of tempers allowing the corrosion resistance properties of the material to be paired with the optimal combination of strength and toughness for the application at hand.

As shown in Table 2, high strength and hardness tempers of C17200, a common BeCu alloy, have strengths and hardnesses equal to or greater than those of 316 stainless steel. This means that components made of C17200 can be integrated into existing steel structures without becoming the weakest link. This provides the added corrosion benefits of BeCu alloys without incurring a strength penalty, resulting

Table 2: Yield Strength, Hardness and Fatigue Strength for 316 austinitic stainless steel and BeCu 17200 Alloy in TF00 and TH04 tempers

Material	**Y.S. (MPa)**	**HRC**	**F.S. (MPa)**
316	1400	22	260
C17200 TF00	1100	40	296
C17200 TH04	1250	42	331

in increased equipment life coupled with easier maintenance.

4 Instrumentation Housings

Downhole instruments and measurement tools, like any other piece of downhole equipment, need to survive the corrosive and abrasive environment of sour gas wells. They also face the added requirement in many cases, that their housings must be made from non-magnetic materials which immediately eliminates steels as possibilities. Measurement while drilling (MWD) instruments are generally located directly behind the drill head so that drilling conditions can be monitored as closely as possible. The result of this type of mounting location is that they are continuously bombarded by abrasive debris and face difficult packaging restrictions. The use of lower strength materials is not an option as the increased size necessary to prove a similar level of protection to the instrumentation would result in their exceeding the dimensions of their packaging envelope.

An added advantage of using BeCu alloys for instrument housings is that these alloys possess excellent castibility as the melt has good fluidity. This means that the often complex shapes required for instrumentation housings can be easily cast out in a minimum number of parts which aids in the environmental sealing of the instrument.

5 Non-Sparking Tools

An interesting property of BeCu alloys is that they are non-sparking. Whereas steel alloys can create sparks when subjected to a sharp impact, friction or the like, which can then become an ignition source in a volatile atmosphere. BeCu alloys do not exhibit these characteristics, making them the only safe choice in sensitive environments.

The defining characteristics of tool steels is that they have large yield strengths and are very hard. BeCu alloys such as C17200 in high strength tempers such as TF00, provide strengths and hardnesses that approach those of traditional tool steels. When the non-sparking behaviour of C17200, is combined with its previously explored strength and hardness properties they quickly emerge as being ideal for making tools for use in environments containing explosive vapors.

While BeCu tools will not possess the same strength and hardness as a true tool steel and therefore will wear more quickly, they will handily outperform other options such as aluminum bronze. The result is a tool that dramatically decreases the chances of a spark thus increasing safety while retaining properties nearly as good as a traditional steel tool.

6 Conclusions

The oil and gas industry operates in harsh, unforgiving environments that can quickly destroy equipment. The combination of a corrosive and abrasive environment with severe loading conditions necessitates the use of the strongest, toughest and corrosion resistant materials available. Beryllium copper alloys provide the strength, fatigue properties and especially the corrosion properties that are so crucial to this industry. They can facilitate quick repairs by reducing corrosion at mating surfaces, and can be substituted for comparable steel parts in critical areas reducing the frequency of required maintenance and the associated costs related to downtime.

Confronted as it is with increased regulation and costs coupled with still recovering market prices, BeCu alloys provide a way to reduce overhead costs by minimizing corrosion related maintenance.

The non-magnetic and non-sparking properties of BeCu alloys provide further applications where their strength and corrosion resistance can be leveraged effectively. BeCu tools are nearly as strong and hard as their traditional tool steel counterparts and provide the added safety of being non-sparking. Likewise, BeCu instrument cages provide the environmental protection needed for sensitive instruments while also being non-magnetic preventing their interference with instruments.

References

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[2] M. Migahed and I. Nassar, "Corrosion inhibition of tubing steel during acidization of oil and gas wells," *Electrochimica Acta*, 2008.