Properties And Sensitivities Of High Strength Tubular Goods

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INTRODUCTION

High strength tubular goods are not new to the oil industry. They have been in use in the Gulf Coast for about 10 yr and are now becoming quite common in West Texas. Although they have been in use for quite some time, only a few people are fully familiar with the problems associated with their use. It is the purpose of this paper to discuss the problems associated with the use of high strength tubular products in West Texas.

First, it is necessary to define what is meant by "High Strength Materials." For the purposes of this discussion any material with a yield strength greater than 80,000 psi is considered a high strength material. Specifically -- referring to the API designations listed in Table I -- N-80, P-105, and P-110 are the materials which will be discussed. N-80 is included because its yield strength often exceeds the 80,000 psi minimum.

SENSITIVITIES OF HIGH STRENGTH MATERIALS

Failures in high yield strength materials are normally caused by one of the following 3 factors:

1. Damage during handling
2. Manufacturing defects
3. Stress-corrosion-cracking

Any sharp-edged notch or crack in the surface of a material is a point of stress concentration: a point of stress concentration can be likened to driving a wedge into the material. Low strength materials are soft and ductile and will yield to relieve the stress, while High strength materials, by their very nature, have low ductility and cannot yield to relieve the stress concentration. In this case it is like driving a wedge into a brittle material such as stone, and only a slight penetration causes the stone to split. In the case of high strength tubular products a crack will propagate from the point of stress concentration and will continue to failure.

Sharp-edged notches can be put in high strength tubular products through the use of tongs and slips. Figure 1 is an example of a failure caused by tong damage.

Cracks and seams created in tubular products during the manufacturing process can cause a failure in the same manner as a notch induced during running. In most instances the most critical manufacturing defect is not visible to the unaided eye and it is the fine crack or longitudinal seam which cause the most trouble and they can be detected only by magnetic particle, electromagnetic, or ultra sonic inspection. Figure 3 shows cracks on tubing upsets made visible by the adherance of powered iron after magnetization.

"Stress-corrosion cracking" is the name applied to failures caused by the penetration of hydrogen into the lattice structure of a high strength steel. Another term meaning the same thing is "hydrogen embrittlement." Hydrogen atoms present in hydrogen sulfide actually penetrate into the steel. The hydrogen atom is smaller than the lattice structure of steel and it can migrate into the steel similarly to fine sand passing through a course sieve. When 2 atoms of hydrogen come together within the steel a hydrogen molecule is formed and there is about a 20 to 1 expansion. The pressure created by this expansion added to the stress already present, parts the grains and a failure will occur in a brittle material. Such a failure is shown in Figure 2. Low strength materials are ductile and will yield to relieve the stress without failing.

HANDLING AND RUNNING PRACTICES

Even the most flawless piece of high strength casing or tubing can be made almost useless by the careless use of slips and tongs. The improper use of tongs and slips is undoubtedly responsible for more critical damage to casing and tubing than all other things put together. The circled area in Figure 1 shows

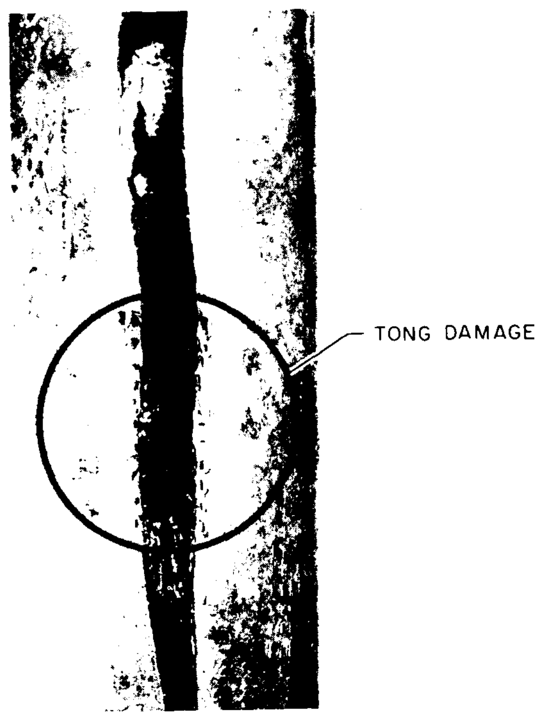

FIGURE 1

CASING BURST
DUE TO TONG DAMAGE

FIGURE 2

BRITTLE FAILURE

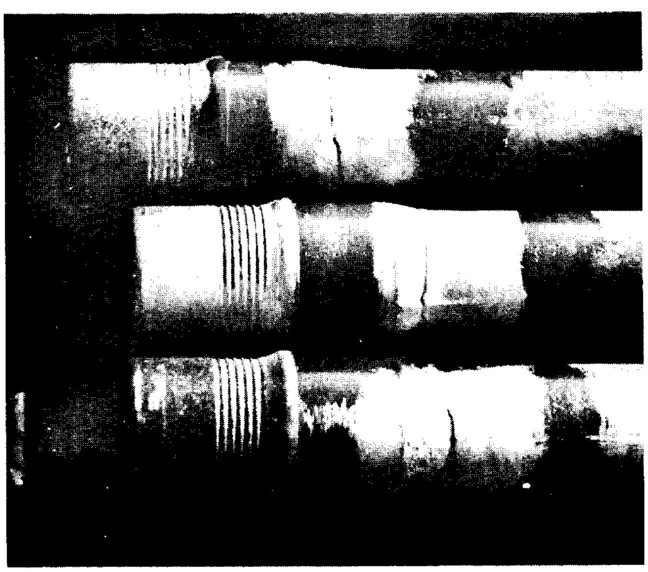

FIGURE 3

DEFECTS ON TUBING UPSETS

the tong marks responsible for this casing burst failure. Undoubtedly there are many down-hole casing failures caused by damage inflicted during the running operation, but it is only rarely that the defective piece is recovered.

Good handling and running practices are desirable for all casing and tubing, but they are absolutely essential for high strength materials. Not only is damage more apt to cause failure, but also the cost of failures in the deeper wells using high strength casing and tubing is considerably higher than for shallower wells.

For convenience the discussion of handling and running practices has been divided into the following 4 major categories:

1. Handling from rack to stabbing.
2. Stabbing and make-up.
3. Slips and elevators.
4. Welding.

First, the thread protectors should be removed and the threads thoroughly cleaned and inspected on the rack. Any damaged threads or sealing surfaces should be repaired or the joint set aside. Next, the pin end protectors should be screwed all the way back on before any attempt is made to roll the casing. Some provision should be made to see that the pipe is carefully lowered to the walk and not allowed to slam against the pipe on the opposite rack. The pin end protector should not be removed until the casing has been pulled into the derrick. Care should be exercised to avoid striking the pipe against any equipment while pulling it into the derrick. A rope hold-back should be used at the Vee door to catch the lower end of the pipe as it swings into the derrick.

Before the pin is stabbed into the box, clean thread compound should be applied to both the pin and box to assure proper make-up. If the thread is not thoroughly lubricated or is lubricated with dirty compound, the desired make-up torque may be attained before the joint is actually fully made up.

In stabbing, lower casing carefully to avoid injuring threads. Stab vertically, preferably with the assistance of a man on the stabbing board. Rubber tubing stabbing guides are available from some specialty tubing manufacturers. Power casing tongs are really essential for today's deep wells to conserve time and to obtain uniform make-up. The pipe should be rotated slowly at first to see that it is not cross-threaded. Also, a direct reading torque gage in the tong line should be used. A pressure gage on air tongs is unsatisfactory because the torque exerted for a given pressure is dependent upon the condition of the air motor and the amount of lubricant used.

Only sharp-clean dies should be used in the power tongs which should never be allowed to slip around and scar the casing. Any attempt to wedge something into a tong to make it grip will result in unequal loading and a tendency to crush the casing or tubing. Also, the tongs should be kept level, and the tong and back-up lines should pull only in a horizontal direction. The use of a broad face, back-up tong is advisable. Only slip-type elevators should be used on long strings of casing, and they should be equipped with sharp, clean dies. The slip setting actuator should be examined frequently to assure that the slips are setting properly. Casing strings should be picked up and lowered carefully, and care should be exercised in setting the slips into the spider to avoid stopping the downward movement of the casing or tubing with the slips. Also, the casing should not be allowed to fall free, even for a short distance, after encountering a bridge or ledge in the hole. Extreme care is necessary at this point to avoid extreme shock loads which can loosen joints or cause a tension failure. Lift plugs can be used to pick up special integral joint tubing.

Casing and tubing spiders should be level to insure uniform engagement of each slip. Examination of the gripping pattern on the surface of the pipe will show whether or not the slips are gripping evenly.

Welding on all high strength tubular goods including N-80 should be avoided. Welding in spots will cause brittleness and cracks because of the quenching action of the large mass of cold steel surrounding the weld area. Heating larger areas of heat-treated pipe can in effect temper it and lower its yield strength. The new thread-looking compounds now available have proven satisfactory in preventing the back-off of float and shoe joints of casing. Also, mechanical locking devices are available for attaching scratchers and centralizers

MANUFACTURING DEFECTS

As previously stated, high yield strength materials are particularly sensitive to defects. API Tentative Standard 5AX covering P-105 tubing and P-110 casing provides for magnetic particle inspection of the finished product. However, Specification 5A covering N-80 and other grades specifies a 12 1/2% defect limit, but it does not provide for inspection. Therefore, N-80 materials going into a stress-corrosion environment or specialty items like heavy-wall, high-strength tubing not covered by API specifications should be inspected prior to use to eliminate lengths containing defects. Some operators have all P grade materials inspected by a service company even though they have been inspected at the mill.

Transverse cracks, such as shown in Figure 3, and longitudinal seams are particularly critical defects. Figure 3 shows transverse cracks picked up by magnetic particle inspection on tubing upsets. Upset areas of high strength tubular goods are subject to crack formation during the quenching operation because the greater wall thickness causes uneven cooling during quenching operations.

STRESS-CORROSION ENVIRONMENT

Before getting into the materials which should be used in a stress-corrosion environment, we have a need to define more precisely what constitutes a stress-corrosion environment. As the name implies, there must be stress present. This can be in the form of tension, burst, or collapse forces. Also, there must be a source of nascent (atomic) hydrogen. Most frequently hydrogen sulfide is the source of the nascent hydrogen. There is evidence to indicate that acid containing arsenic as a high temperature corrosion inhibitor can provide the hydrogen atoms also

Field experience backed up by lab analysis has indicated that trace amounts of hydrogen sulfide in a dry gas well are sufficient to cause failure. In one instance a tubing failure occurred in a high pressure dry gas well where field tests had indicated no hydrogen sulfide present. The failure occurred after 6 months even though the well remained shut-in. Lab analysis of the failure showed clear evidence of nydrogen enbrittlement. Dry gas wells are particularly critical because there is no liquid film protecting the metal surface

MATERIALS FOR USE IN STRESS-CORROSION ENVIRONMENTS

As stated above, there must be some stress present in the material for failure to occur. How high the stress can go before it becomes critical depends upon the material. It is now the consensus of many metallurgists familiar with the problem that a material's susceptibility to hydrogen embrittlement can be correlated with its hardness and strength. Figure 4 is a graph showing how the critical stress level varies with the Rockwell C hardness number. Approximate yield strengths for the various hardness numbers are shown also. For different alloys these yield strength values would vary some.

Figure 4 shows that materials with a Rockwell C hardness of 24 or less can be used safely to a stress level equal to 80% of their yield strength in a stress-corrosion cracking environment. It also indicates that the usable strength of a steel drops rapidly at hardness values exceeding Rc 24. In fact, it drops to such a degree that materials with hardnesses greater than Rc 24 are not suitable for this type of environment. This means that the P grade materials are not suitable where they are exposed to a stress-corrosion environment.

What yield strength corresponds to a Rockwell C hardness of 24 depends upon the composition of the steel and the heat treatment used. The yield strength values shown on Figure 4 are approximate or average values. Specific information regarding the particular steel is needed when ordering tubular goods which will be subjected to a stress-corrosion cracking environment.

Table I lists the physical properties as specified for the various grades of API tubular products. It can be seen that there is no specification covering compo-

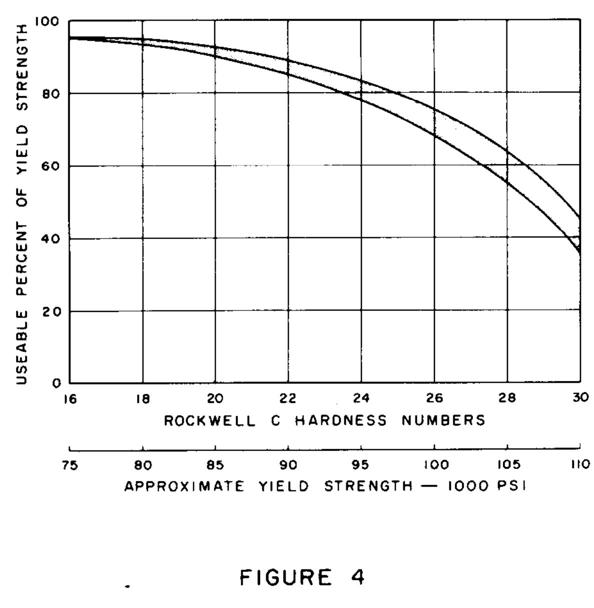

FIGURE 4

USEABLE YIELD STRENGTH FOR HYDROGEN SULFIDE ENVIRONMENT sition or hardness. For instance, N-80 could nave a yield strength as high as 110,000 psi which, according to the correlation shown in Figure 4, would be an approximate hardness of Rc 30. This would make it entirely unsuitable for this type service. Tubing or casing made to J-55 specifications is satisfactory, but more data than provided by API specifications are needed to determine whether N-80 is satisfactory. The P grade materials, however, can be ruled out.

The American Iron and Steel Institute and the Society of Automotive Engineers have set up specifications covering the chemical composition of steels. Table II lists 2 steels AISI 4140 and 4340 which are used quite often in oil wells. Table III gives the properties of 1 of them, AISI 4340, for various tempering temperatures. From this it can be seen that it is not only necessary to specify the AISI type steel, but it is also necessary to specify the minimum tempering temperature to get the desired strength and hardness.

Recognizing this problem the API is now working on a specification covering casing and tubing for sulfide service. These specifications will cover the tempering temperature as well as lower and upper yield strengths. At the present time a limited yield N-80 tubing with a yield strength range of 75,000 - 90,000 psi can be obtained from some pipe mills for the price of N-80 plus 7.5%. In some instances operators are hardness checking N-80 materials before using them in critical wells.

TABLE I

API PHYSICAL PROPERTIES

GRADE	MIN. YIELD	MAX. YIELD	MIN. TENSILE
J-55	55,000	80,000	75,000
N-80	80,000	110,000	100,000
P-105	105,000	135,000	120,000
P-110	110,000	140,000	125,000

TABLE II

AISI-SAE STEEL SPECIFICATIONS

AISI-SAE NUMBER	CHEMICAL COMPOSITION LIMITS PER CENT C	Mn	Ni	Cr	Mo
4140	0.40	0.85	—	1.0	0.20
4340	0.40	0.70	1.80	0.80	0.25

TABLE III

PHYSICAL PROPERTIES OF AISI 4340 STEEL

NORMALIZED AT 1625-1725 °F
QUENCHED IN OIL AT 1475-1550 °F

TEMPERING TEMP. °F	YIELD STRENGTH 1000 PSI	TENSILE STRENGTH 1000 PSI	HARDNESS R_C SCALE
800	190	210	44
900	175	195	42
1000	158	178	38
1100	138	160	35
1200	119	140	30
1300	95	120	23

INDUSTRY DESIGN TRENDS

For a while the oil industry seemed to be in a headlong dash toward the use of higher and higher strength tubular products. In the case of tubing, however, this trend has somewhat reversed. A close look at Figure 4 shows the reason. Tubing is in constant contact with the well fluids and if cracking agents are present high strength materials are not as effective as low strength materials. To combat high pressure, heavy-wall low-strength materials are being used. In deep wells where tension in the main factor tapered tubing strings are being used.

The main problem is early determination of whether or not stress-corrosion cracking agents are present. Since, from the standpoint of timing, this is difficult on an individual well basis, some companies are using a pressure and depth criteria for determining the need for low hardness materials. One such approach is to automatically assume that all dry gas wells with 4000 psi or greater shut-in tubing pressure are potentially critical. Another approach is to classify certain reservoirs as being critical.

Undoubtedly in time much more knowledge will be gained along the lines of how to make high strength tubular goods with greater ductility. However, at the present time it is necessary to use high strength casing and tubular products with a great deal of care.

REFERENCES

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