Summary Description:

The requirements in oil and gas applications, especially in drilling applications, are increasing constantly. New drilling technologies need materials that can fulfill challenging requirements regarding mechanical, magnetic and corrosion properties.
New oil and gas fields are explored in larger depth under the sea, for these explorations new materials should be developed. These new materials have to show high strength with a yield strength higher than 1035 MPa (150 ksi) and excellent corrosion properties in aggressive environments due to the combination of high temperature and salinity of drilling fluids.
Deutsche Edelstahlwerke has developed a new material solution that meets the demanding requirements for drilling applications. The newly developed non-magnetic high interstitial (FeCrMnMo(C+N)) austenitic stainless steel was produced by conventional steel making processes in an induction furnace, subsequent electro slag re-melting, and hot working. This new FeCrMnMo-HIS is characterized by high strength, toughness, and enhanced corrosion properties. After solution annealing, this material is completely austenitic and displays an elongation higher than 60 %, a yield and ultimate strength of 600 MPa (87 ksi) and 980 MPa (142 ksi), respectively, combined with high impact energy, higher 350 J (> 258 ft-lbs). The FeCrMnMo-HIS steel shows no intergranular corrosion without sensitization treatment and no weight loss in ferric chloride solution testing at room temperature for 72 hours and a high pitting potential. The critical pitting temperature is 35 °C (95 °F). Additionally, the HI-Steel is resistance to stress corrosion cracking in saturated NaCl at 108 °C (226 °F).
The outstanding mechanical properties combined with the good corrosion resistance in chloride environments as well as economy-effective production make the new high interstitial (C+N) non-magnetic austenitic stainless steel a very promising alloy for oil and gas applications.

1. What is the innovation?

A new non-magnetic high interstitial (FeCrMnMo(C+N)) austenitic stainless steel has been developed. The outstanding mechanical properties combined with the good corrosion resistance in chloride environments as well as economy-effective production make the new high interstitial (C+N) non-magnetic austenitic stainless steel a very promising alloy for oil and gas applications.

2. How does the innovation work?

A new non-magnetic high interstitial (FeCrMnMo(C+N)) austenitic stainless steel was developed with the nominal composition Fe-18Cr-18Mn-2Mo-1(C+N) (wt. %). The steel was produced by conventional steel making processes. It offers a good combination of elongation, strength and impact energy in solution annealed condition. Pitting resistance equivalent number (PREN) is higher than 35. The high-interstitial (HI) steel shows good resistance to stress corrosion cracking and pitting corrosion in different environments. The new high interstitial FeCrMnMo austenitic stainless steel is a very promising grade for applications in the oil and gas industry due to the high mechanical strength above 1000 MPa (145 Ksi) combined with good corrosion properties. This work started in 2017 and is ongoing.

3. Describe the corrosion problem or technological gap that sparked the development of the innovation. How does the innovation improve upon existing methods/technologies to address this corrosion problem or provide a new solution to bridge the technology gap?

New oil and gas fields have been discovered in large depths under the sea. The exploration tools in these fields are exposed to different rock formations, aggressive environments and high temperatures. The steels used to explore these fields not only need to have a good combination of high strength and high corrosion resistance in aggressive environments but also nonmagnetic properties. High nitrogen FeCrMn-austenitic stainless steels have been used for drilling applications such as non-magnetic drill collars, Measuring While Drilling (MWD), and Logging While Drilling (LWD) housings. They have yield strength above 1000 MPa (145 ksi), good ductility, toughness and excellent corrosion resistance. Super austenitic stainless steels have been used for applications with yield strength above 1035 MPa (150 ksi). The development of new non-magnetic stainless steels which will have higher mechanical properties (YS > 1035), excellent corrosion properties in aggressive environments at high temperatures and better price-performance ratio is necessary. Thus, Deutsche Edelstahlwerke is developing a new non-magnetic high interstitial (FeCrMnMo(C+N)) austenitic stainless steel that can fulfill these demanding requirements necessary in drilling applications.

4. Has the innovation been tested in the laboratory or in the field? If so, please describe any tests or field demonstrations and the results that support the capability and feasibility of the innovation.

A new non-magnetic high interstitial (FeCrMnMo(C+N)) austenitic stainless steel was developed with the nominal composition Fe-18Cr-18Mn-2Mo-1(C+N) (wt. %). The steel (5 t/ 11000 lb) was produced by conventional steel making processes in an induction furnace, subsequent electro slag re-melting, and hot working. After forging and air cooling, the newly developed high interstitial (C+N) steel shows an austenitic structure with precipitates, most likely of type M23C6 and M2N at the grain boundaries and “pseudo-pearlite” which consists of carbonitride and austenite layers.

After forging, the material was solution annealed between 1075 and 1150 °C (1967-2102 °F) for one hour and water quenched. This solution annealing was carried out in the laboratory to determine the optimal temperature to dissolve precipitates and achieve a homogeneous austenitic microstructure without precipitates. The optimal solution annealing temperature for this FeCrMnMo-HIS should be 1125 °C (2057 °F) in order to have an 100% austenitic microstructure with nitrogen and carbon completely in solid solution.

Mechanical properties were evaluated according to ASTM A370, i.e. tensile and Charpy-V tests as well as hardness. The microstructure was characterized by optical and scanning electron microscope. Intergranular corrosion resistance was measured using ASTM A262 Practice A and E methods. Pitting resistance and critical pitting temperature (CPT) were evaluated according ASTM G48 and electrochemical method (ASTM G61-86). Stress corrosion cracking was evaluated according to ASTM G 36. It was conducted in saturated NaCl at 108°C under a tensile load of 310 MPa (45 ksi) for up to 1000 hours. Corrosion tests were performed on the newly developed FeCrMnMo-HIS after solution annealing at 1125 °C (2057 °F) for 1 hour and water quenching. All test specimens were machined in mid-radius position in longitudinal direction.

The newly developed FeCrMnMo-HIS with a fully austenitic microstructure presents a good combination of elongation (> 60 %), notch-impact toughness (> 350 J (258 ft-lbs) at room temperature) and yield strength and UTS higher than 600 MPa (87 ksi) and 980 MPa (142 ksi), respectively (Figure 1).

The material does not show intercrystalline corrosion acc. to ASTM A 262 Practice A. After sensitization treatment (675 °C/1 h/Water), however, the material is susceptible to intergranular corrosion according to ASTM A 262 Practice E due to the precipitation of different carbides or nitrides. The new FeCrMnMo-HIS does not show weight loss at room temperature, while the corrosion rate is 7.11 mm/y at 50 °C (122 °F). Critical pitting temperature is 35 °C (95 °F).

Pitting corrosion resistance of FeCrMnMo-HIS in 3.56 wt. % sodium chloride at room temperature was compared with super austenitic stainless steel 1.4563 (UNS N08028/ X1NiCrMoCu31-27-4) and high nitrogen FeCrMn austenitic stainless steels. The FeCrMnMo-HIS and high nitrogen FeCrMn show similar open circuit potential (OCP), while the super austenitic steel has higher OCP. The FeCrMnMo-HIS shows a higher Epit than the super austenitic stainless steel and high nitrogen FeCrMn austenitic stainless steel. The stress corrosion cracking test was conducted in saturated NaCl at 108 °C (226 °F) under a tensile load of 310 MPa (45 ksi) for up to 1000 hours. The material does not present any cracks or pittings after the stress corrosion cracking test at 310 MPa (45 ksi) within 1000 hours.

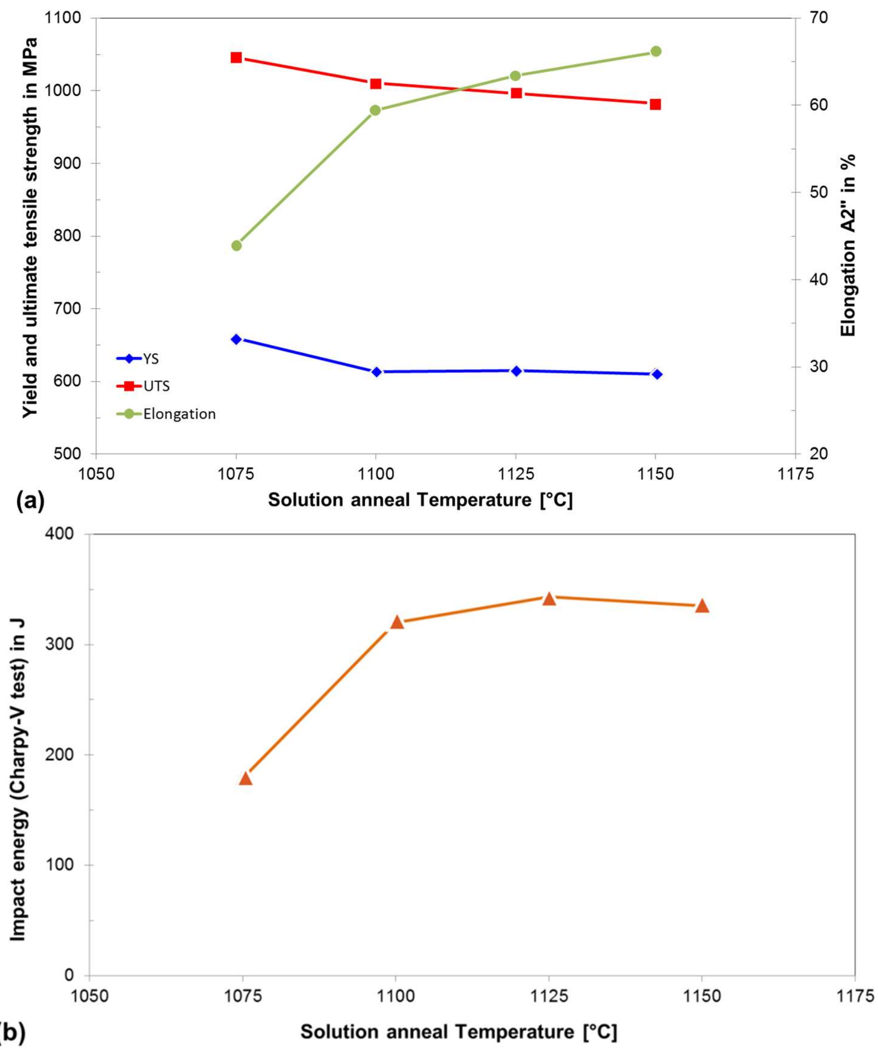

Figure 1: Influence of solution annealing temperature on mechanical properties. (a) Yield, ultimate tensile strength and elongation at rupture (A2”). (b) Impact energy

Table 1:
Electrochemical Parameters of FeCrMnMo-HIS and 1.4563 (UNS N08028) in 3.56 % NaCl at room temperature.

Electrochemical Parameters	Alloy			
	FeCrMnMo-HIS	**FeCrMn**	**FeCrMnMo**	**1.4563 (UNS N08028)**
PREN*	36 - 38	29 – 30	29 - 32	37.7 – 44.4
MARC**	36 - 39	21 - 23	21 - 23	30 -37
OCP (after 1h) [mV]	90	94	96	177
E_{pit} @ 100 μA/cm^2 [mV]	1384 ±55	440	632	1236 ±6

* PREN = %Cr + 3.3 • %Mo + 16 • %N

** MARC = %Cr + 3.3 • %Mo + 20 • %N + 20 • %C - 0.5 • %Mn - 0.25 • %Ni

5. How can the innovation be incorporated into existing corrosion prevention and control activities and how does it benefit the industry/industries it serves (i.e., does it provide a cost and/or time savings; improve an inspection, testing, or data collection process; help to extend the service life of assets or corrosion-control systems, etc.)?

Deutsche Edelstahlwerke is developing a new non-magnetic high interstitial (FeCrMnMo(C+N)) austenitic stainless steel whose shows an excellent combination of mechanical and corrosion properties. This new steel can be used in oil and gas applications where high strength is necessary in very aggressive environments.

6. Is the innovation commercially available? If yes, how long has it been utilized? If not, what is the next step in making the innovation commercially available? What are the challenges, if any, that may affect further development or use of this innovation and how could they be overcome?

The innovation is not commercially available.

The new non-magnetic high interstitial (FeCrMnMo(C+N)) austenitic stainless steel has been tested in solution annealed condition up to now. A new production route has been developing to increase the mechanical properties (YS > 1035 MPa). The material will be strain hardened via thermomechanical processing. After this process, thorough characterization will be carried out. This will include not only mechanical and corrosion properties but also fatigue properties according to requirements for oil and gas applications, in special in drilling conditions.

7. Are there any patents related to this work? If yes, please provide the patent title, number, and inventor.

No related patents.