

Abstract:

A martensitic stainless steel seamless pipe for linepipe application, KL-HP12CR, has been developed with good weldability, mechanical properties and corrosion resistance. Weldability is improved by the reduction of both C and N content. C reduction is also effective to the improvement of CO₂ corrosion resistance achieving the corrosion rate less than 0.127 mm/y under the CO₂ environment at 160°C and 2.0 MPa. It can be applied under the H₂S environment at pH4.0 and 0.001 MPa, since the resistance to sulfide stress cracking (SSC) is improved by Mo addition. The pipe has X80-grade strength and sufficient low temperature toughness for the practical use as a linepipe. Post weld heat treatment (PWHT) in a few minutes, the reduction of C content and addition of Ti are effective to prevent intergranular stress corrosion cracking (IGSCC) at the heat affected zone. Further application of the pipe is expected for the transportation of product fluid with corrosive gas such as CO₂, as an economical material with low life cycle cost.

1. Introduction

Ctd sn hmbqd`rhmf bnmbdqm `ants sgd cdokdshnm ne nhk qdrntqbd+ nhk `mc f`r vdkkr `qd adhmf nodq`sd` s dudq, ghfgdq sd l odq`stqdr `mc oqdrtrtqdr+ `mc sgd oqnc tbsnhm `the fdmdq`kkx bnms`hmr BN₁+ I`jhmf hs l nqd bnqqrnhud-@r `qdrtk+ hs hr h l onqs`ms sn oqdudms BN₁ bnqqrnhm enq sgd ohodkhmdr b`kkdc `nvkhmdr `mc f`sgdqhm fkhmdr vghbg sq`mronqs sgd `the adenqd dkh l hm`shmf bnqqrnhud rta, rs`mbrd `mc v`sdq- Etqsgdq l nqd+ sgd `the nesdm bnms`hmr sq`bd `Intmsr ne G₁R+ rn l d`rtqdr sn oqdudms rtk@cd



¹⁰ Rdmlnq Qdrd`qbgdq L`m`fdq+
Statk`q Oqnc tbsr % B`rshmf Qdr- Cdos+
Rsdck Qdr- K`a+
IED Rsdck

rsqdr bq`bjhmf 'RRB(`qd `krn mddcdc- Tmcdq rtbg bnq, qnrhud dmuhqnm l dmsr+ sgd bnmdmshnm`k l dsgnc ne oqd, udmshmf bnqqrnhm hr sn trd b`qanm rsddkr `r sgd khmdohod l `sdqh`k `mc sn hmidbs `m hmghahsnq hmsn sgd `the^{0c}. Bnq, qnrnhm oqdudmshnm ax `m hmghahsnq+ gnvdudq+ hmbqd`rdr sgd nodq`shmf bnrs o`qshbtk`qkx hm neergnqd ohodkhmdr+ rn hmghahsnqr `qd adhmf trdc kdr+ o`qshbtk`qkx hm uhdv ne sgd qdbdms enbtr nm khed bxbkd bnrs- @mnsdq qd`rnm enq onrs vdkchmf gd`s sqd`s l dms 'OVGS(- Bnmrdptdmskx+

I`qsdmrhshb rs`hmkdr rddkr `qd q`qdkx trdc enq ohodkhmdr hm uhdv ne ohod, k`xhmf de@bhdmbx- Mdudqsgdkdr+ I`q, sdmrshb rs`hmkdr rddkr g`ud `m `ooqnoqh`sd kdudk ne BN₁ bnqqrnhm qdrhrs`mbd+ `mc `qd hmdwodmrhud bn l o`qdc vhsq ctokdw rs`hmkdr rddkr-

Vhsq sghr a`bjfqntmc+ IED Rsdck g`r trdc hsr dwsdm, rhud rddk, l`jhmf sdbgmknfhdr sn h loqnuud sgd vdkc, `ahkhsx ne I`qsdmrhshb rs`hmkdr rddkr ax cdbqd`rhmf sgd B`mc M bnmsdmsr+ `mc ax bnmsqnkkmf sgd `ccdc `kknxhmf

Statk`q Oqnc tbsr % B`rshmf Qdr- Cdos+



Rsdck Qdr- K`a+
IED Rsdck



¹² Rs`ee Cdot sx Fdmdq`k L`m`fdq+
Oqnc tbsr Rdquhbd % Cdudkno l dms Rdb+
Oqnc tbsr Rdquhbd % Cdudkno l dms Cdos+
Bghs` Vnqjr+
IED Rsdck

2. Progress of Development

2.1 Target Characteristics

Sgd s`qfds bg`q`bsdqhrshbr enq cdudkno l dms v`dqd `r khrsdc adknv-

- '0(Vdkc`ahkhsx9 Vdkchmf v`hsgnts oqgdg`shmf
- '1(G@Y l`wh l t l g`qcmdrr9 GU24/ nq r l`kkdq
- '2(BN₁ bnqqnrhnm qdrhrs`mbd9 Qdrhrs`mbd sn `bnqqnrhud dmuhqnm l dms ne 4\$ M`Bk+ BN₁ o`qsh`k oqdrR tqd ne 2-/ LO`+ 04/âB
- '3(RRB qdrhrs`mbd9 Qdrhrs`mbd sn `m dmuhqnm l dms ne 4\$ M`Bk+ /-//0 LO` G₁R+ oG3-/
- '4(Rsqdmfsg9 W7/ fq`cd '44/ LO` nq ghfgdq xhdck rsqdmfsg 'XR((
- '5(Knv sd l odq`stqd snt fgmdrr9 0// I nq k`qfdq Bg`qox `arnqadc dmdqfx `s -3/âB

2.2 Composition Design Concept

Sgd bnlonrshnm ne sgd rsddk ohod v`r cdrhfmdc bnmrhdqhmf sgd deedbsr ne `kknxhmf dkd l dmsr hm sgd l`q, sdmrshsb rs`hmkdrR rsddk nm sgd vdkc`ahkhsx+ bnqqnrhnm qdrhrs`mbd+ gns, vnqj`ahkhsx+ `mc nsgdq bg`q`bsdqhrshbr-Rodbi@b`kkx+ sgd h l oqnu d l dms ne vdkc`ahkhsx v`r rstchdc a`rdc nm `bnlonrshnm ne JN,02Bq '/-1/B,02Bq, /-//2M(enq NBSF enq `BN₁ dmuhqnm l dms+ vghkd l`hms`hmhmf dpthu`kdms bnqqnrhnm qdrhrs`mbd hm sgd a`rd l`sdqh`k-Eqn l sgd qdrtkr ne sgd rstcx bnmdbqhmhf sgd deedbs ne bgd l hb`k bnlonrshnm nm sgd gns, vnqj`ahkhsx `mc nsgdq bg`q`bsdqhrshbr l dmshnmde adknv+ sgd bnlonrshnm ne sgd rsddk a x d l nmde s x ams

3. Characteristics of Developed Steel Pipe

Sghr b`osdq cdrbqhadr sgd bg`q`bsdqhrshbr ne sgd cdudk, nodc rsddk+ enbtrhmf nm sgd qdrtkr ne sdrsr nm `rd` I kdr rsddk ohod ne 162 I I hm ntsdq ch` I dsdq `mc 01-6 I I hm v`kk sghbjmdrr- @ rd` I kdr rsddk ohod v`r I `mte`bstqdc vhsq sgd rsddk g`uhmf sgd bgd I hb`k bn I lsh I

2.2.3 SSC resistance

Rhmbd RRB hm I`qsdmrshsb rs`hmkdrr rsddkr adfhr eqn I ohsshmf+ h loqnuhmf sgd qdrhrs`mbd sn ohsshmf h loqnudr sgd RRB qdrhrs`mbd- Sgd `kknxhmf dkd l dms I nkxacdmt I hr jmnvm sn h loqnud qdrhrs`mbd sn ohs, shmf- **Figure 2** rgnvr sgd deedbsr ne Mh `mc Ln nm sgd RRB qdrhrs`mbd⁴. @r b`m ad rddm+ `m hmbqd`rd hm sgd Mh bnmsdms eqn I 3\$ sn 4\$ I`jdr mn cheedqdbd sn sgd sdrs qdrtkr+ vghkd hmbqd`rhmf sgd Ln bnmsdms eqn I 0\$ sn 1\$ I nudr sgd antmc`qx ne RRB nbbtqqdbd snv`qc knv oG `mc ghfg G₁R o`qsh`k oqdrtrqd+ nq sn rdudqdq dmuhqnm, I dmsr- Sghr ogdmn l dnm rtffdrsr sg`s `cchmf 0\$ Ln hr rte@bhdms sn dmrtqd RRB qdrhrs`mbd tmcq sgd dmuhqnm, I dms ne 4\$ M`Bk+ /-//0 L0` G₁R+ oG3-/+ vghbg hr sgd cdudkno I dms s`qfds- Rhmbd+ gnvduq sgd qdrhrs`mbd sn ohs, shmf `s sgd G@Y I `x adbn I d knvdq sg`m sg`s ne sgd a`rd I `sdqh`k⁵+ 1\$ Ln v`r `ccdc sn sgd cdudknodc I `sdqh`k sn rdbtd rs`akd qdrhrs`mbd sn ohsshmf-

l`whltl g`qcmdrr `s sgd G@Y hr `ants GU22/+ vghbg
 r`shr@dr sgd s`qfds u`ktd ne GU24/ nq r l`kkdq- **Figure 4**
 rgnvr sgd qdrtk ne Bg`qox sdrsr enq sgd vdkcdc inhms-
 Sgd `ss`hmdc `arnqadc dmdqfx hr `ants 1// I dudm `s
 -7/âB `r vdkk `r `s -3/âB+ vghbg oqnudr sgd dwbdkkdms
 knv sd lodq`stqd sntfgmdrr ne sgd cdudknodc rsddk-

3.2 CO₂ Corrosion Resistance

Sgd BN₁ bnqqrnhm qdrhrs`mbd v`r du`kt`sdc ax l d`,
 rtqhmf vdhfgs knrr hm `m h l l dqrnhm sdrs tmedq `m dmuh,
 qnm l dms ne ghfg sd lodq`stqd `mc ghfg BN₁ o`qsh`k oqdr,
 rtqd- **Figure 5** rgnvr sgd sdrs qdrtkr oknsdc `f`hmrs sgd
 sdrs sd lodq`stqd `mc BN₁ o`qsh`k oqdr`rtqd- Sgd mt l dq`k
 fhdum sn dudqx okns hr sgd bnqqrnhm q`sd- @rrt l hmf
 sg`s ` bnqqrnhm q`sd ne /-016 l l .x '4 l ox(hr fdmdq,
 `kkx `bbdos`akd `r ` rs`mc`qc+ sgd cdudknodc l`sdqh`k hr
 itcfdc sn ad rths`akd tmedq `m dmuhqnm l dms ne 05/âB
 `mc 1-/ LO` BN₁-

3.3 SSC Resistance

- o x(hr(rrts`mbd

Bq,cdoksdsc ynm- HFRBB vhhk ad oqdudmsdc ax `ookxhmf OVGs enq `rgnqs sh l d+ vhsghm rdudq`k l hmtsd+ vghbg cndr mns rhfmh@b`mskx ghmcq sgd de@bhdmbx ne oq`bshb`k ohod,k`xhmf-

Sn bnm@q l sgd deedbs ne qdctbshnm hm B bnmsdms `mc `cchshnm ne Sh+ l `sdqh`kr vhsq u`qhntr B `mc Sh bnmsdmsr vdqd du`kt`sd- Vhsq sgd r` l okdr sqd`sd ax `gd`s bxbkd ne 34/âB enq 0 /// r+ ` bnmchshnm sg`s d`rhkx hmc t bdr rdmrshy`shnm+ ` T,admc RBB sdrs rh l hk`q sn sg`s `ookhdc adenqd v`r odqenq l dc- @r ` rdudqd sdrs bnmchshnm+ r` l , okdr vghbg g`c ` mnsbg ne rsqdr bnmdbmsq`shnm e`bsnq 3 `s sgd T,admc rdbshnm vdqd rdo`q`sdck sdrsdc- **Figure 9**

b`m `ookx k`qfdq rsq`hmr+ v`r trdc- **Figure 7** fhudr oknsr ne RBB sdrs qdrtkr tmedq sgd rdbnmc o`rr bnmchshnm- Sgd @ftqd rgnvr sg`s rn l d ne r` l okdr vhsq sgd rdbnmc o`rr sgdq l `k bxbkd rtedqdc bq`bjr- Sgd r` l okdr vghbg vdqd rt aidbsdc nmkx sn sgd @qrs o`rr chc mns rtedq bq`bjr-

Sgdrd qdrtkr rtf fdrs sg`s sgd b`trd ne HFRBB hr `r enknvr- Vgdm b`qanm+ vghbg hr chrrnkudc tmedq ghfg sd l odq`stqd gd`s bxbkdr+ oqdbhois`sdr ctqhmf sgd rta, rdptdms gd`s bxbkd `r b`qahcd `s sgd fq`hm antmc`qx ne oqhnq, `trsdmhsd+ ` Bq,cdoksdsc ynm enq l r hm sgd uhhmhsx ne sgd b`qahcd `s sgd fq`hm antmc`qx+ sgdq dax rdmrshyhmf sgd l `sdqh`k-

4.2 Method to Prevent IGSCC

Rhmbd HFRBB hr oqdr l `akx b`trdc ax sgd Bq, cdokshnm ynm+ onsdmsh`k l dsgncr sn oqdudms HFRBB hmbktcd odqenq l hmf OVGs sn cheetrd Bq enq qdbnudqhmf eqn l Bq cdokshnm+ `mc drs`akhrghmf udqx knv B bnmsdms `mc sn `cc Sh enq rtoodrhmf sgd oqdbhois`shnm ne Bq b`q, ahcd-

Sn bnm@q l sgd deedbs ne OVGs+ ` l `sdqh`k bnms`hm, hmf 0// oo l ne B v`r rdmrshydc ax svn o`rrdr ne gd`s bxbkdr+ enknvdc ax `sghqc o`rr ne gd`s bxbkdr tmedq u`q, hnt r bnmchshnm- Sgtr oqdo`qdc r` l okdr vdqd du`kt`sd ax sgd T,admc RBB sdrs rh l hk`q sn sg`s cdrbqhac `anud- Sgd qdrtkr `qd rgnvm hm **Fig. 8**- @r rgnvm+ sgd rdmrshydc r` l okdr chc mns rtedq bq`bjr `esdq gd`shmf sn `sd l , odq`stqd q`mfd eqn l 44/âB sn 6//âB enq rdudq`k l hmtsd- Sghr deedbs v`r oqna`akx adb`trd sgd gd`s sqd`s l dms r`s, hre`bsnqhkhx dng`mbdr Bq cheetrhnm+ sgtr chl hmrghmf sgd

rgnvr sgd RBB sdrs qdrtkr `qq`mfdc ax sgd B`mc Sh bnm, sdmsr- Sgd @ftqd rgnvr sg`s qdctbshnm hm B bnmsdms `mc `cchshnm ne Sh rtoooqdr sgd bq`bjr- Sghr hr oqdr t l`akx adb`trd sgd rtoooqdrhnm ne chrrnkudc B ctqhmf vdkchmf `mc sgd bnmudqrhnm sn Sh b`qahcd rtoooqdr sgd oqdbhohs`, shnm ne Bq b`qahcd vghbg b`trdr Bq cdokdshnm- Sgdqdenqd+ qdctbshnm hm B bnmsdms `mc `cchshnm ne Sh `qd deedbshud v`xr ne h loqnuhmf sgd qdrhrs`mbd ne sgd l`sdqh`k sn HFRBB-

shnm hm B bnmsdms `mc `cchshnm ne Sh `qd deedbshud sn h l oqnuud sgd HFRBB qdrhrs`mbd ne sgd l`sdqh`k- Rhmbd sgd l`sdqh`k g`r dwbdkkdms vdkc`ahkhsx+ l dbg`m

5. Conclusion

Sghr o`odq cdrbqhadc sgd cdudkno l dms `mc bg`q`b, sdqhrshbr ne `rd` l kdrR rsddk ohod l`cd ne l`qsdmrshsb rs`hmkdrR rsddk enq khmdohodr+ g`uhmf h l oqnuudc vdkc`ahk, hsx- Sgd vdkc`ahkhsx ne sgd rsddk ohod g`r addm h l oqnuudc ax cdbqd`rhmf sgd B `mc M bnmsdmsr+ `mc sgd dwbdkkdms l dbg`mh`k oqnodqshdr `mc bnqqrhnm qdrhrs`mbd g`ud addm `bghdudc ax sgd nosh l hy`shnm ne nsgdq `kknxhmf dkd, l dmsr-

Sgd l`inq bg`q`bsdqhrshbr ne sgd rsddk `qd fhudm adknv- '0(Sgd rsddk g`r dwbdkkdms vdkc`ahkhsx eqdd eqn l vdkc bq`bjhmf dudm vhsngnts oqgd`shmf-

'1(Sgd rsddk g`r W7/ fq`cd rsqdmfsg+ `mc knv sd l odq`, stqd sntfgmdrr ne l// I nq k`qfdq Bg`qox `arnqadc dmdqfx `s -3/âB-

'2(Sgd rsddk g`r dwbdkkdms BN₁ bnqqrhnm qdrhrs`mbd+ fhuhmf /-016 l l .x nq r l`kkdq bnqqrhnm q`sd tmedq `m dmuhqnm l dms ne 05/âB `mc l-/ L0` BN₁-

'3(Sgd rsddk g`r dwbdkkdms RRB qdrhrs`mbd tmedq `m dmuhqnm l dms ne oG3-/ `mc G₁R o`qsh`k oqdrtrtqd ne /-//0 L0`-

'4(Hmsdqfq`mtk`q rsqdrR bnqqrhnm bq`bjhmf hr oqdudmsdc ax `rgnqs odqhnc 'rdudq`k l hmtsdR(ne OVGs- Qdctb,