



Corrosion Behavior of X80 Pipeline Under HVDC Interference

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OUTLINE

Background of pipeline SCC in China

Corrosion Behavior of Pipeline Steel under HVDC Interference

Conclusions

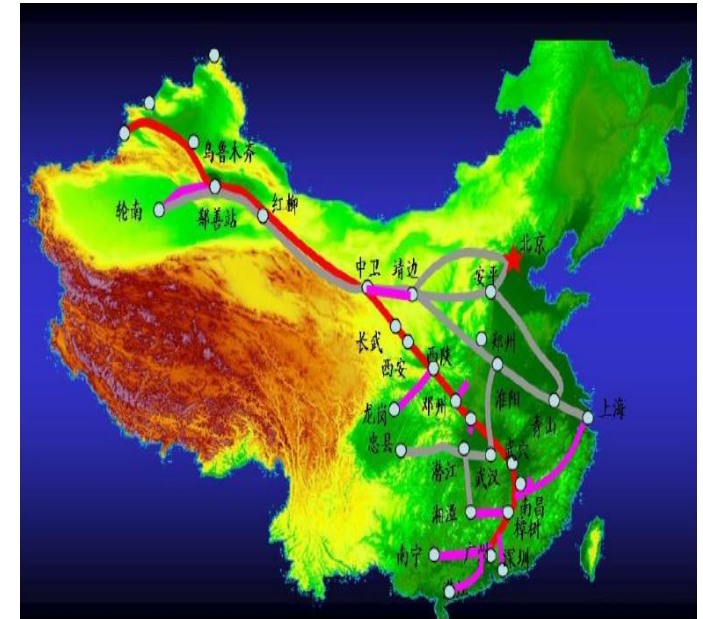


Background

- Since 1958, when the first long-distance crude oil pipeline was built in China, the construction of oil and gas pipelines has developed rapidly in the past 60 years in China .
- The pipeline construction in China has reached to about 3000-9000 km annually after 2000. By 2025, the total pipeline length of China will be more than 240,000 km.

Development targets of pipeline

Type	2015	2025	Average annual growth rate
Total mileage (km)			
Crude oil pipeline (km)	27,000	37,000	3.2%
Product oil pipeline (km)	21,000	40,000	6.7%
natural gas pipeline (km)	64,000	163,000	9.8%



Medium and long term oil and gas pipeline network planning in 2017. (National Energy Administration)



Background

According to the investigation of pipeline failure in recent years, there was no report of typical stress corrosion cracking. However, there is still a potential risk of stress corrosion cracking.

- After the 1990s, more than **85%** pipes were 3PE pipe with heat-shrinkable sleeve joint;
- Most of the pipe had been in operation for more than **10 years**, some pipe more than **20 years**;
- Large diameter, high steel grade and high pressure increased gradually. (**X70/X80 2,300km**)
- **HVDC** transmission technology has emerged fast.



Coating damage



Cathodic disbonding



Corrosion perforation

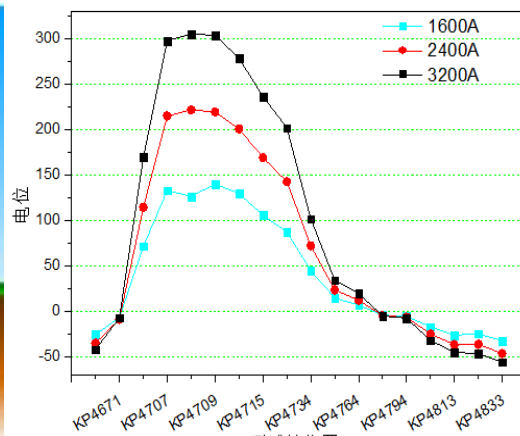
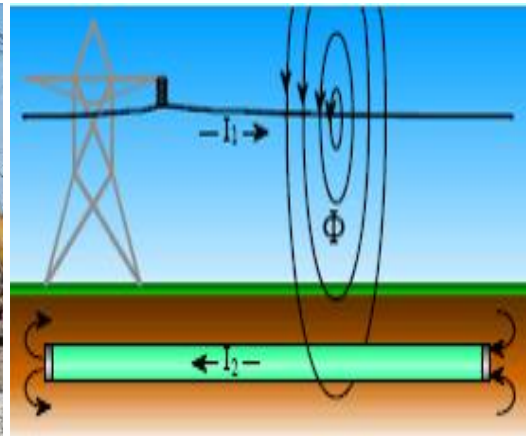


Background-HVDC status in China

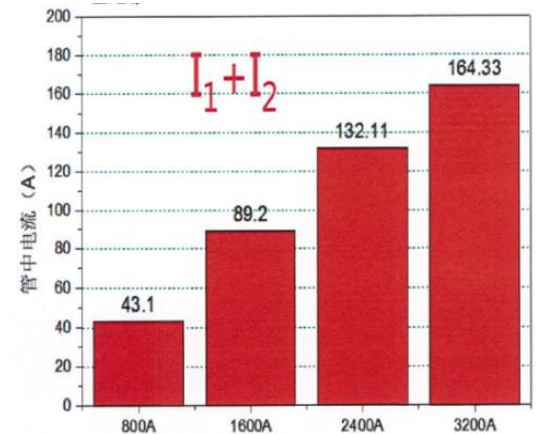
- By the end of 2007, China had put into operation 10 HVDC projects, including 7 projects above 500KV. At present, China has the longest transmission distance, the highest voltage grade and the largest capacity in the world.
- The rated current of the newly ($\pm 1100\text{kV}$) Huaidong-Huadong HVDC transmission line can reach 5000A.
- The interference between pipeline and high-voltage transmission lines has become a problem that cannot be ignored.



serious interference to the buried steel pipeline nearby



pipe-ground potential deviation exceeds **300V**



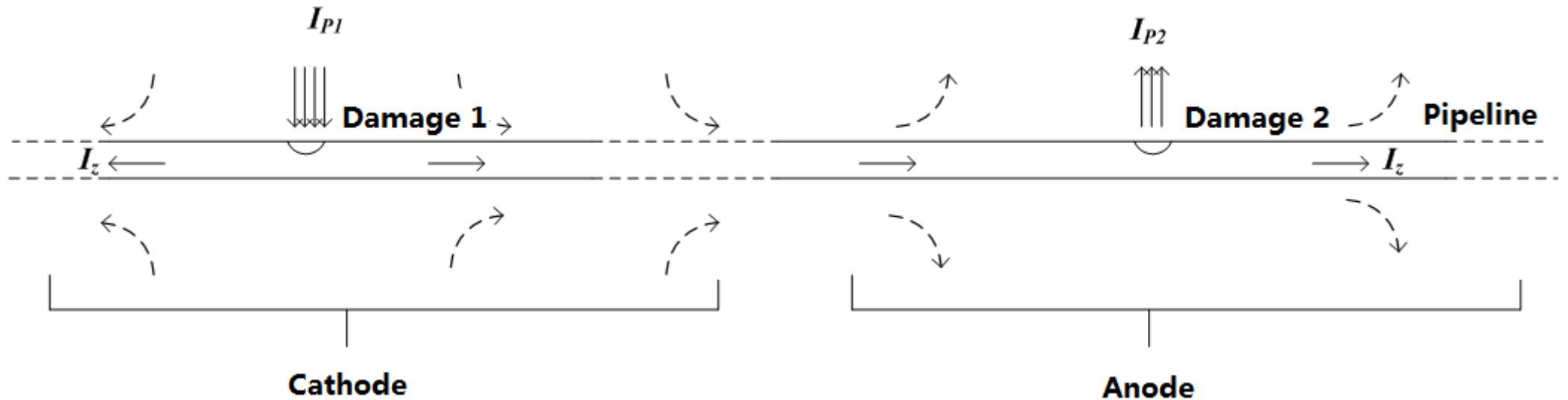
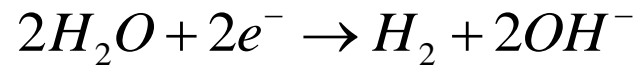
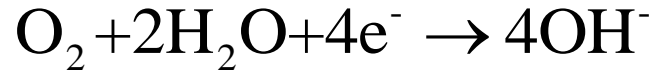
grounding current more than **100A**



Background

Mechanism of HVDC grounding pole interference

grounding electrode operate with single-pole induced high current into the ground



Oxygen reduction reaction or hydrolysis reaction

Corrosion of metals



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Experiment

- ❑ **2.1 Cathode interference (Hydrogen-induced damage):** monitoring the influence of hydrogen damage
- ❑ **2.2 Anode interference (Corrosion):** monitoring the corrosion behavior in the process of HVDC interference



Hydrogen-induced damage test



HVDC interference



Experiment

Hydrogen embrittlement sensitivity index

$$I_{HE} = \frac{\psi_0 - \psi_H}{\psi_0} \times 100\%$$

ψ_0 — reduction area of an uninterferenced sample/%, ψ_H — reduction area of an interferenced sample/%

Criteria in engineering: $> 35\%$ - fracture, $25\sim 35\%$ - damage, $< 25\%$ - safety

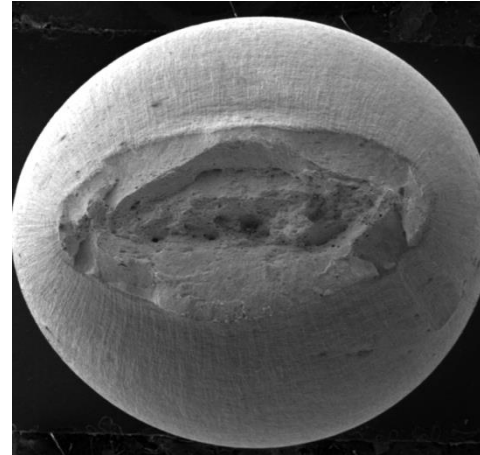
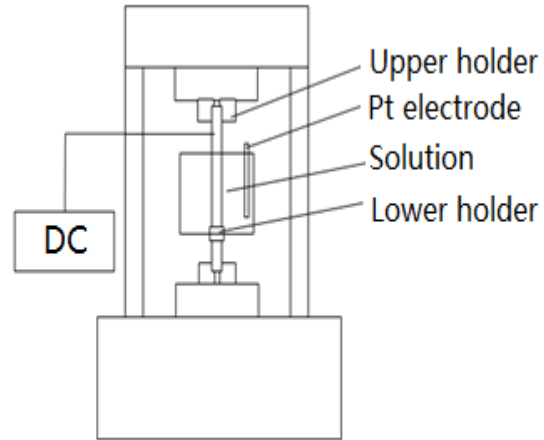
Criteria for determining hydrogen damage of alloys in NASA8-30744

The degree of damage	Extreme damage	Severe damage	Damage	No damage
I_{HE}	$> 50\%$	$25\sim 50\%$	$10\sim 25\%$	$< 10\%$

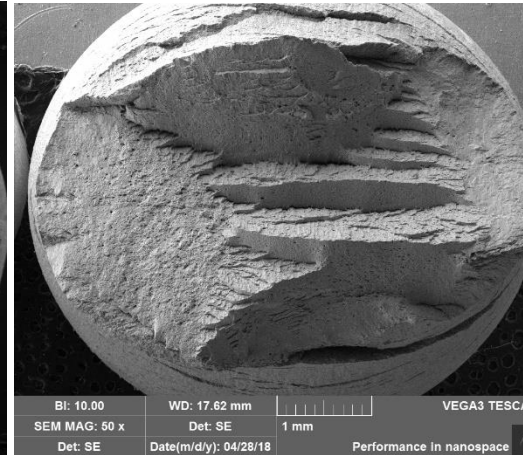


Results and discussion--Cathode interference

2.1.1 Effect of **current density** on the fracture characteristics of X80



$I=0\text{mA/cm}^2$



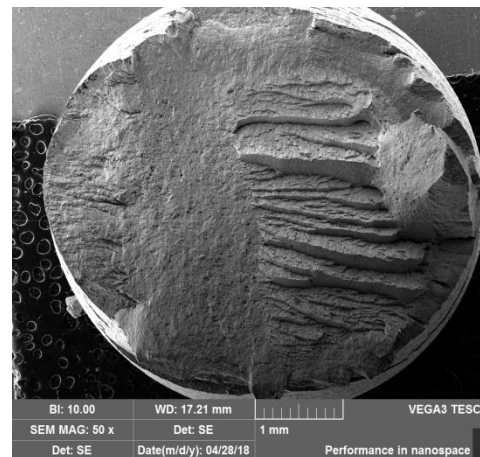
$I=10\text{mA/cm}^2$



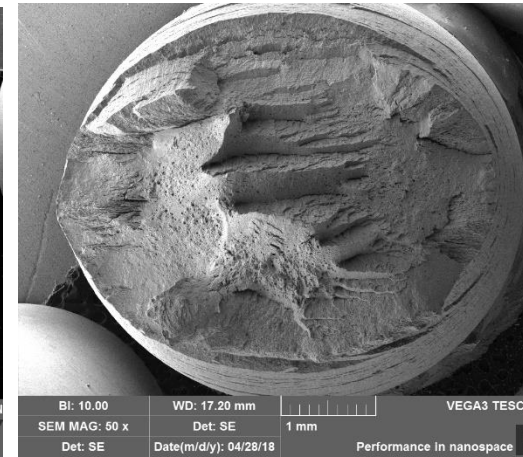
$I=20\text{mA/cm}^2$

Experimental parameters

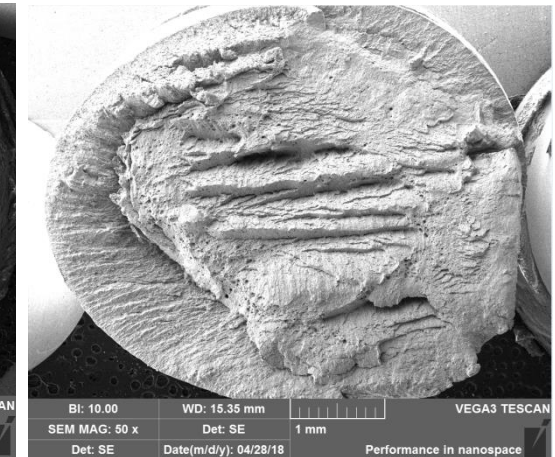
- Solution NS4
- Tensile rate =0.1mm/min



$I=30\text{mA/cm}^2$



$I=40\text{mA/cm}^2$



$I=50\text{mA/cm}^2$

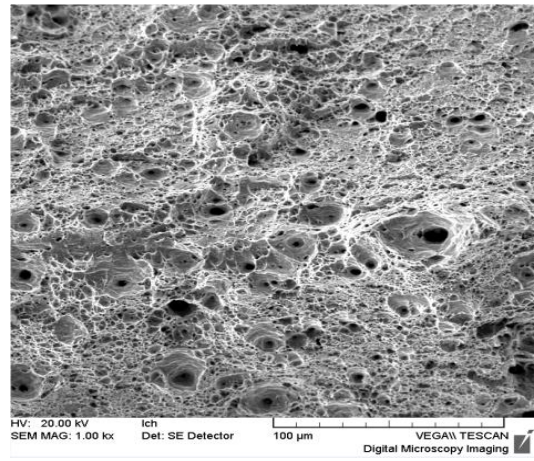
- ✓ Several **cracks** appeared near the fracture surface
- ✓ **Brittle characteristic** zone on fracture surface



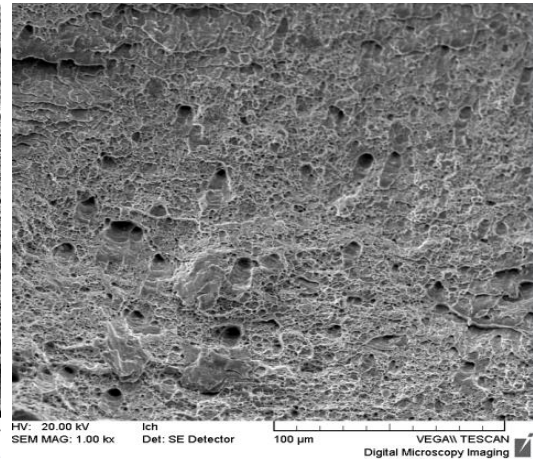
Results and discussion--Cathode interference

□ Effect of **current density** on the SEM morphology of X80 fracture

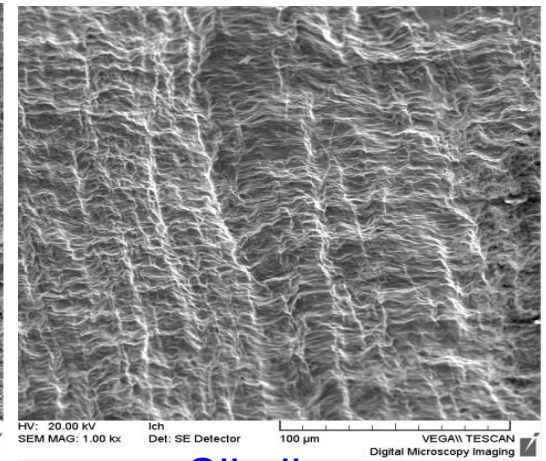
Non interference



Center-Dimple

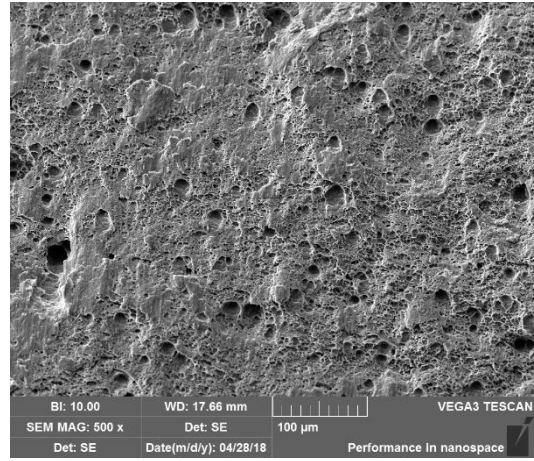


Shear lip-Dimple

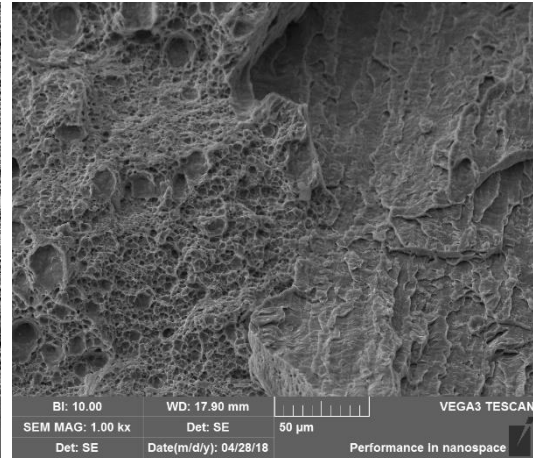


Slip line

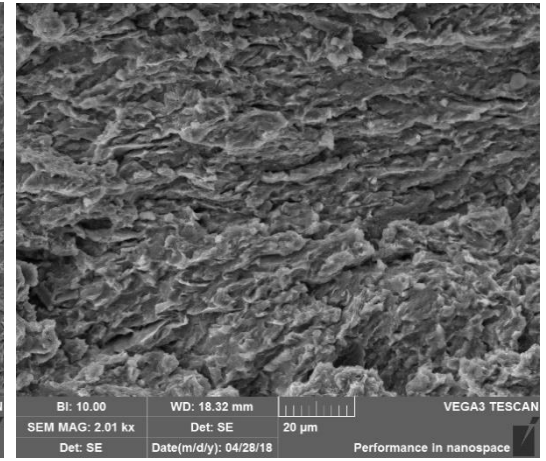
Interference



Center-Dimple



Ductile-brittle junction



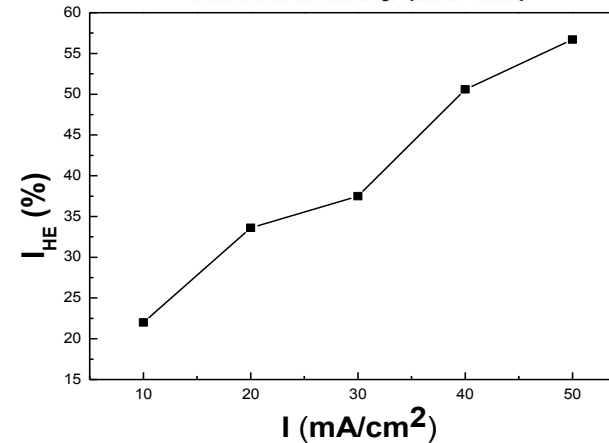
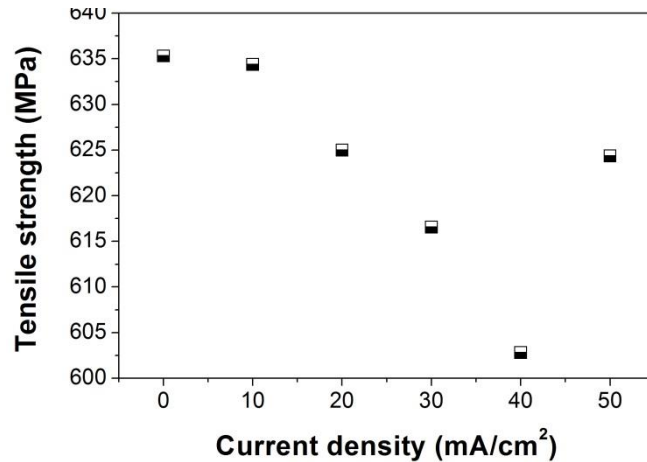
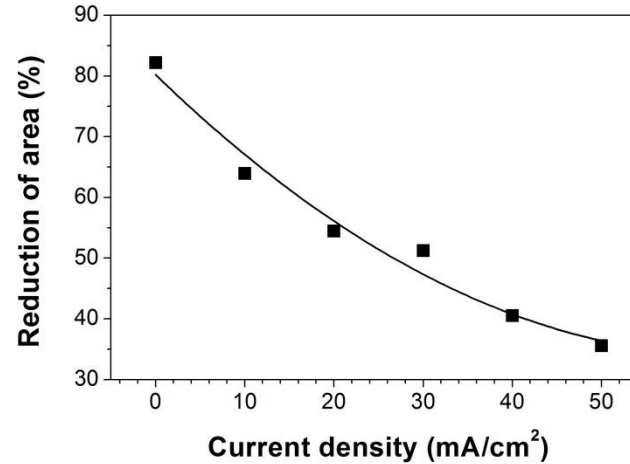
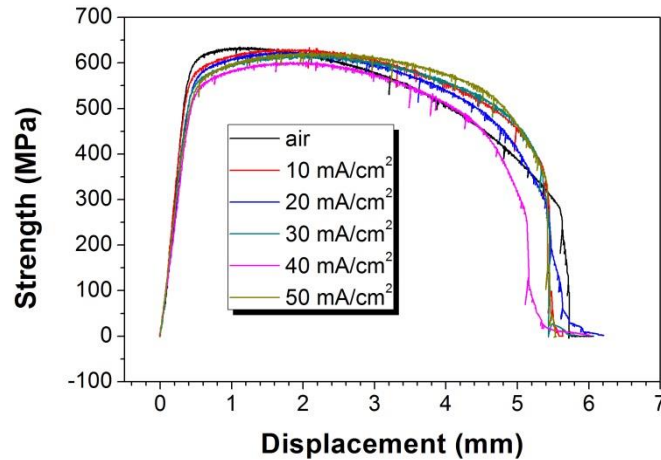
Quasi cleavage

Brittle fracture characteristics appeared on fracture surface



Results and discussion--Cathode interference

□ Effect of **current density** on the mechanical properties of X80



- ✓ The tensile strength decreased slightly as the current goes up, the maximum change is 22MPa.
- ✓ The reduction of area **decreased** and the material **plastic loss was obviously** with the increasing of current density, there is a higher risk of brittle fracture when $I > 20 \text{ mA/cm}^2$.

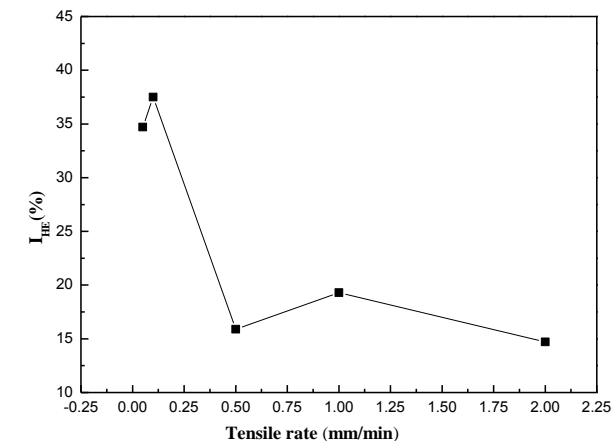
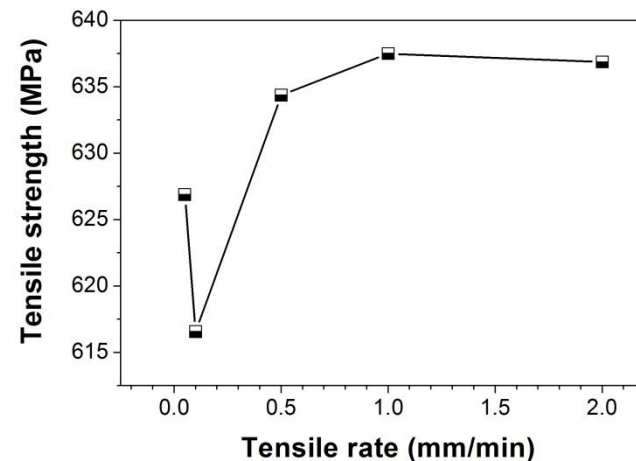
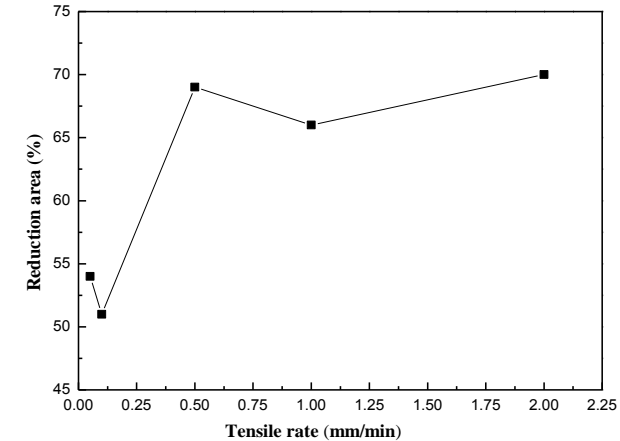
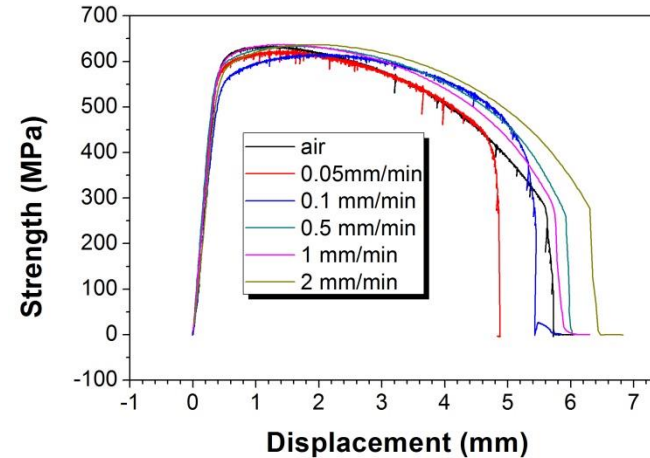


Results and discussion--Cathode interference

2.1.2 Effect of tensile rate on the mechanical properties of X80

Experimental parameters

- Solution NS4
- $I = 30\text{mA/cm}^2$

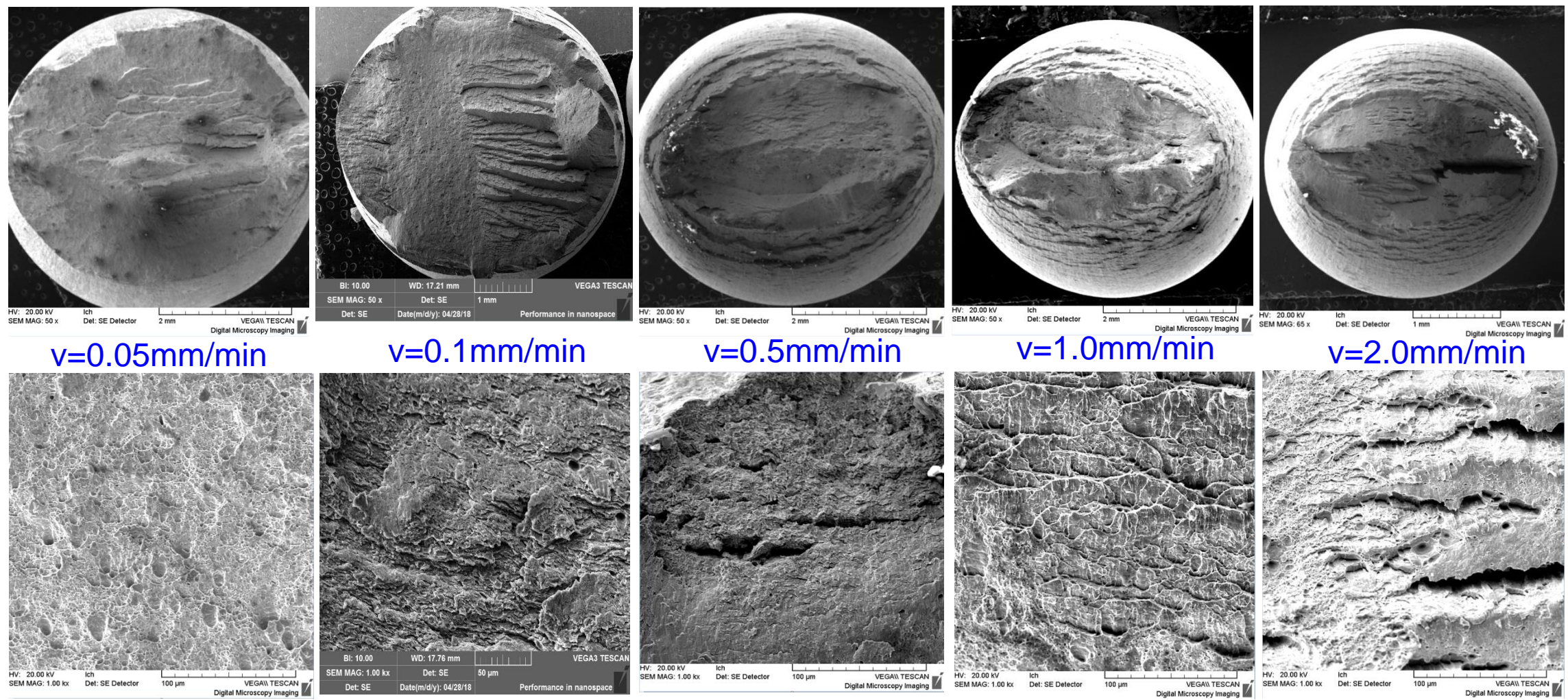


- ✓ With the increase of tensile rate, the fracture time was significantly **shortened**, reduction area **goes up**, and sensitivity **dropped**.
- ✓ The lower tensile rate supplied enough hydrogen charging time and benefited for the invasion of hydrogen atoms, when $v > 0.5\text{mm/min}$ the risk of brittle reduced.



Results and discussion--Cathode interference

□ Effect of **tensile rate** on the fracture morphology of X80



v=0.05mm/min

v=0.1mm/min

v=0.5mm/min

v=1.0mm/min

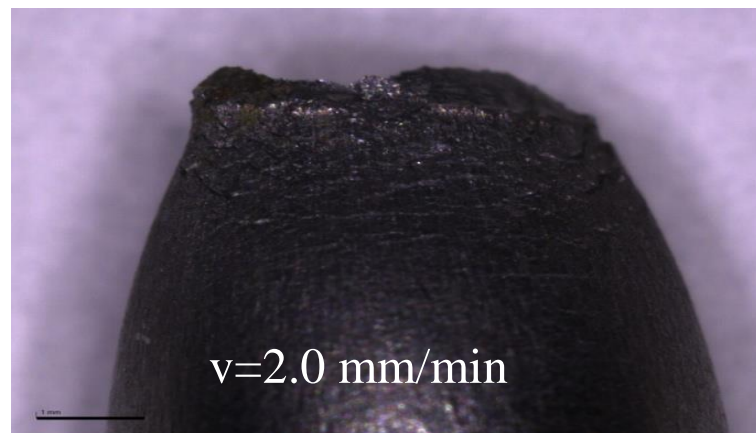
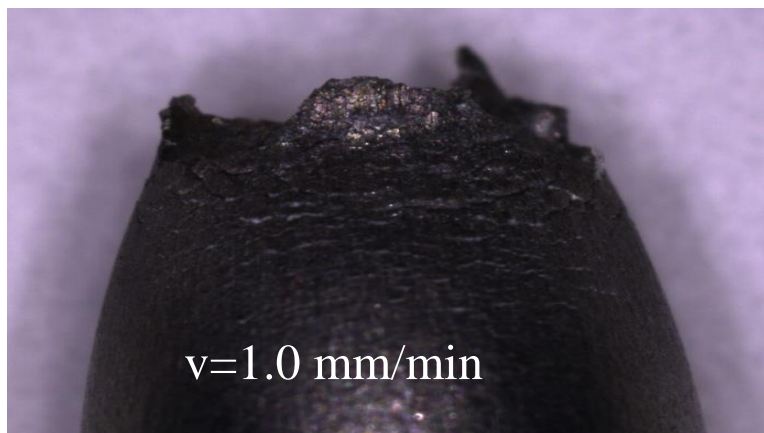
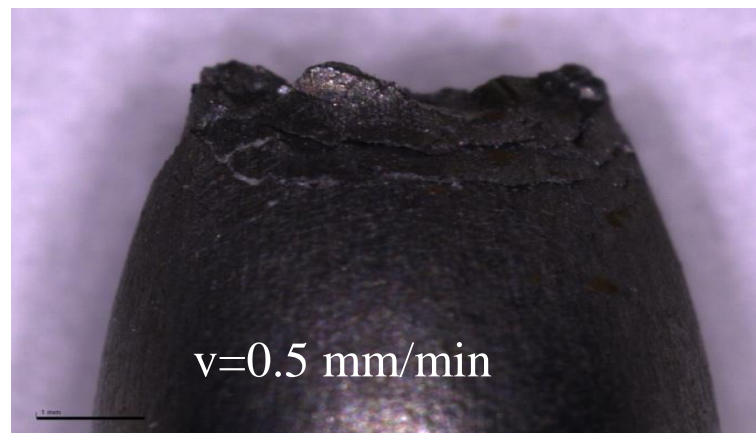
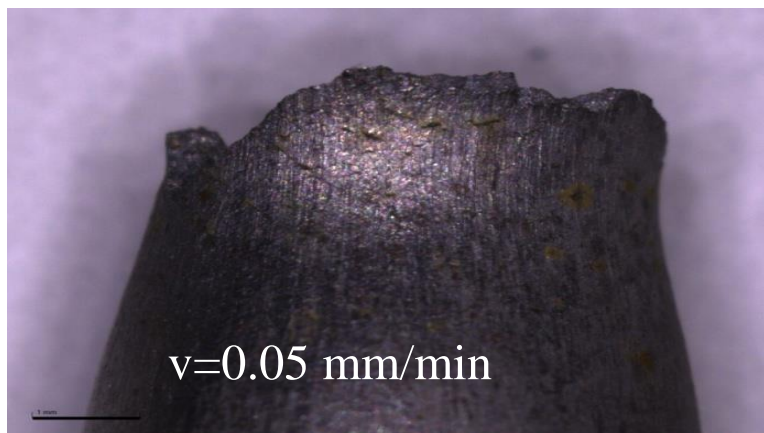
v=2.0mm/min

- ✓ Fracture represents **brittle morphology**.
- ✓ Cracks near the fracture surface increased with the tensile rate increasing.



Results and discussion--Cathode interference

□ Effect of **tensile rate** on the fracture morphology of X80



Crack near fracture

- ✓ With the increase of tensile rate, the size and density of the crack in the side wall of the fracture increased, while the necking increased.
- ✓ The increase of tensile rate promotes the surface crack propagation.

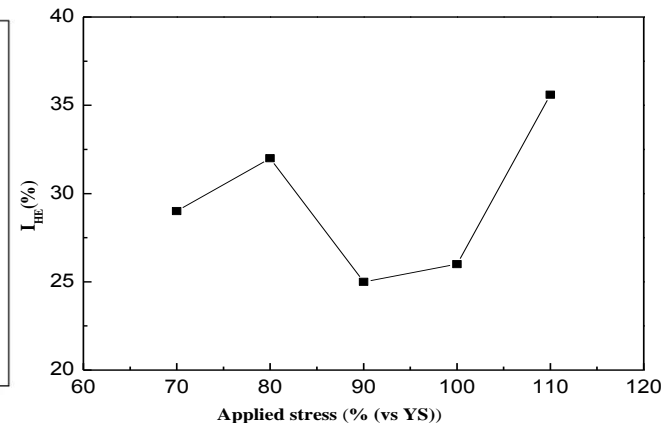
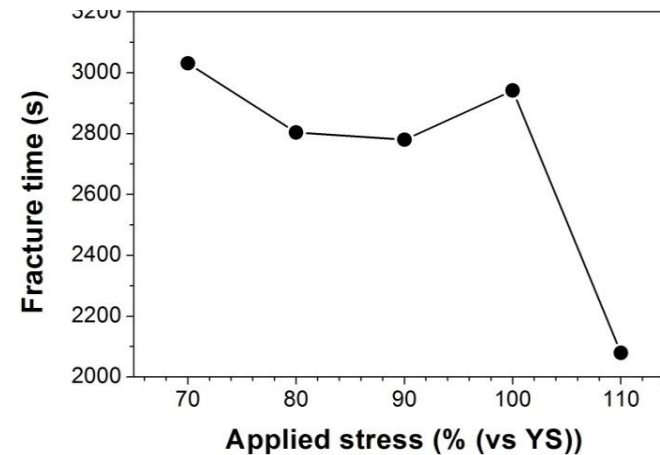
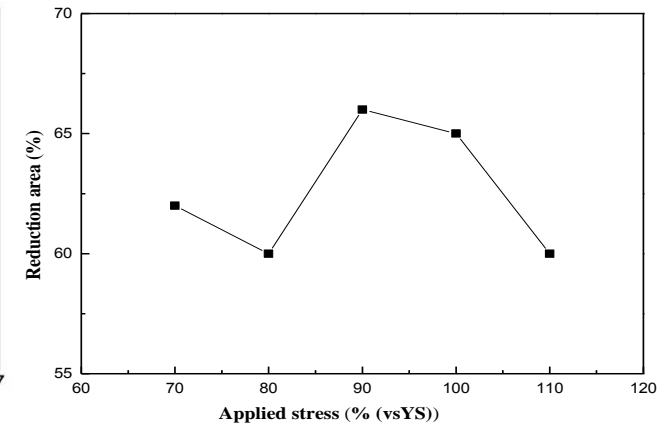
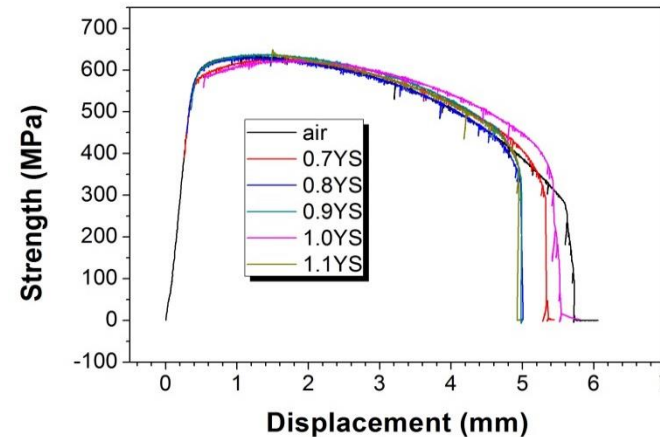


Results and discussion--Cathode interference

2.1.3 Effect of **tensile stress** on the mechanical properties of X80

Experimental parameters

- Hydrogen charging 2h under constant tension loading ($I = 30\text{mA/cm}^2$)
- Constant tensile rate to fracture ($v = 0.1\text{ mm/min}$)

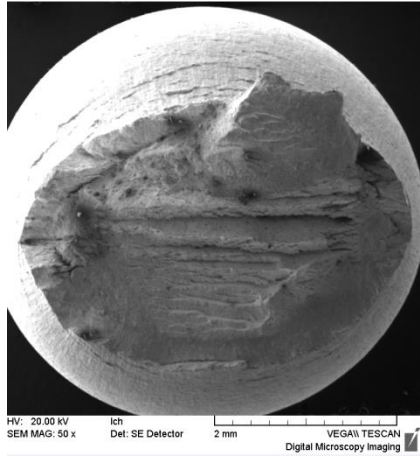


- ✓ When stress less than 100%SMYS, the reduction of area raises with increasing tensile stress.
- ✓ When stress exceed 110%SMYS, the reduction of area decreases greatly.

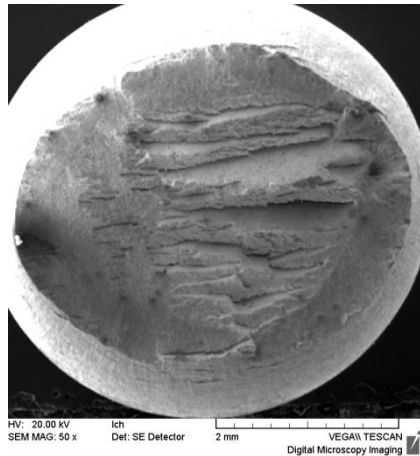


结果与讨论 Results and discussion--Cathode interference

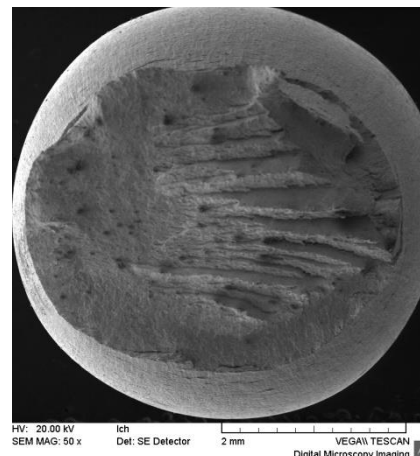
□ Effect of **tensile stress** on the fracture morphology of X80



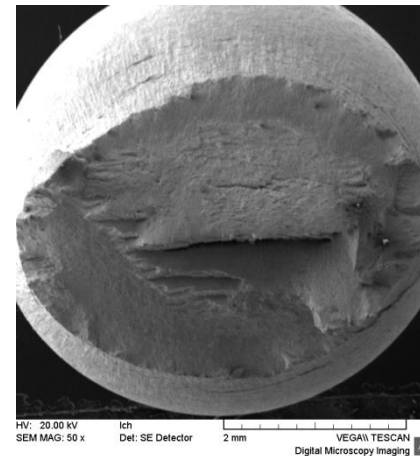
$\sigma=70\%SMYS$



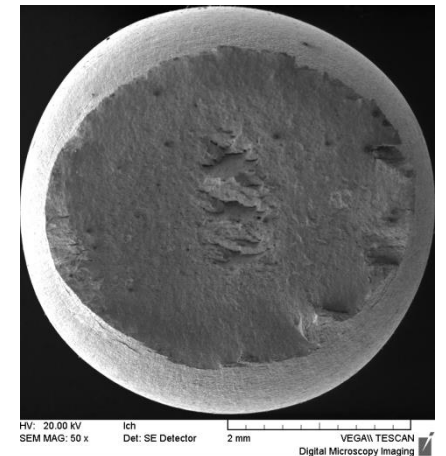
$\sigma=80\%SMYS$



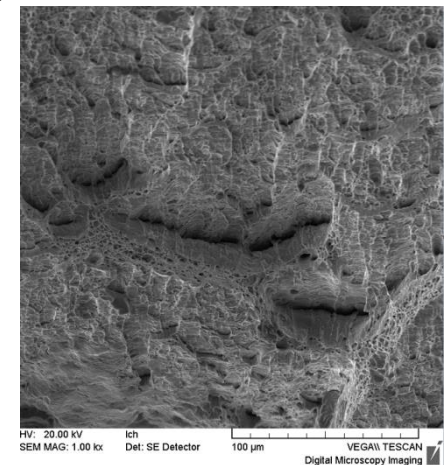
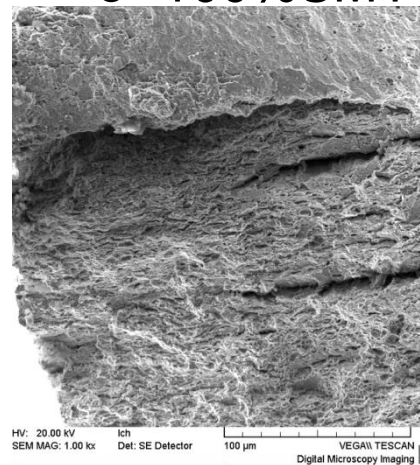
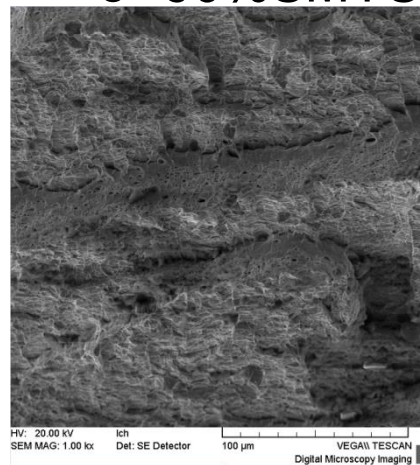
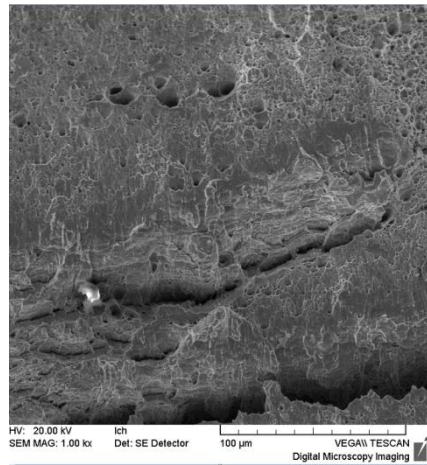
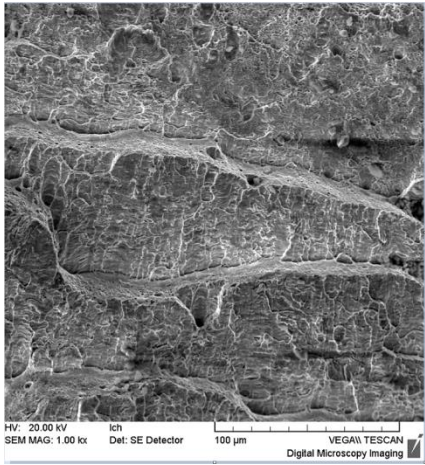
$\sigma=90\%SMYS$



$\sigma=100\%SMYS$



$\sigma=110\%SMYS$



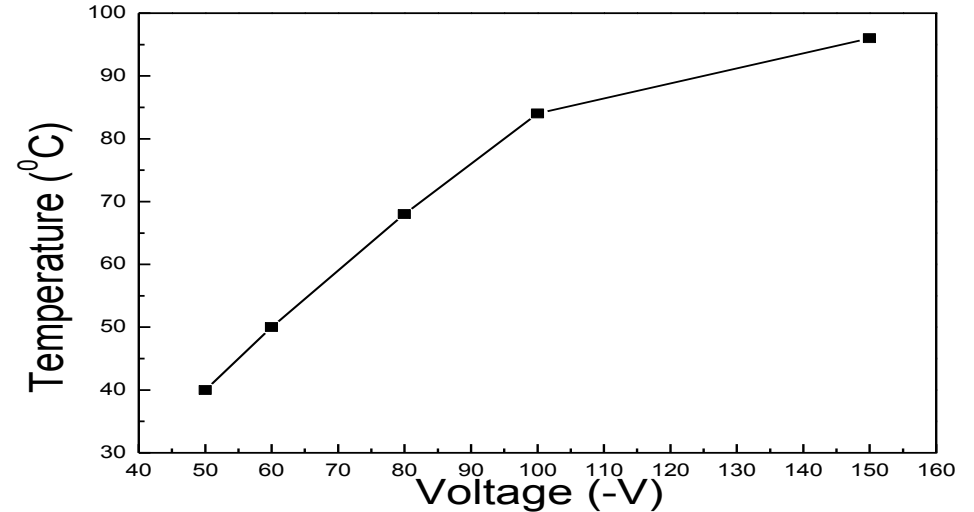
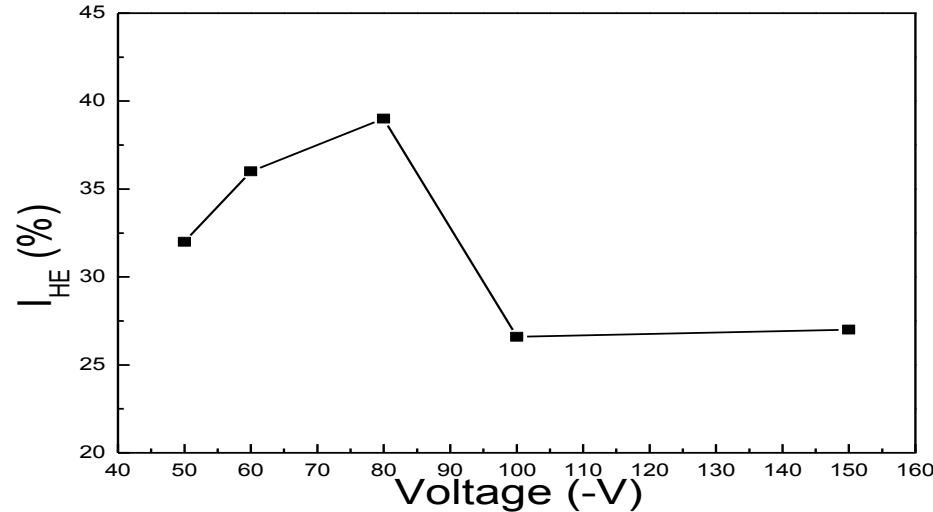
✓ Brittle fracture occurs on all conditions.

✓ Crack density decreased with the tensile stress increasing.



Results and discussion--Cathode interference

2.1.4 Effect of **interference voltage** on the mechanical properties of X80

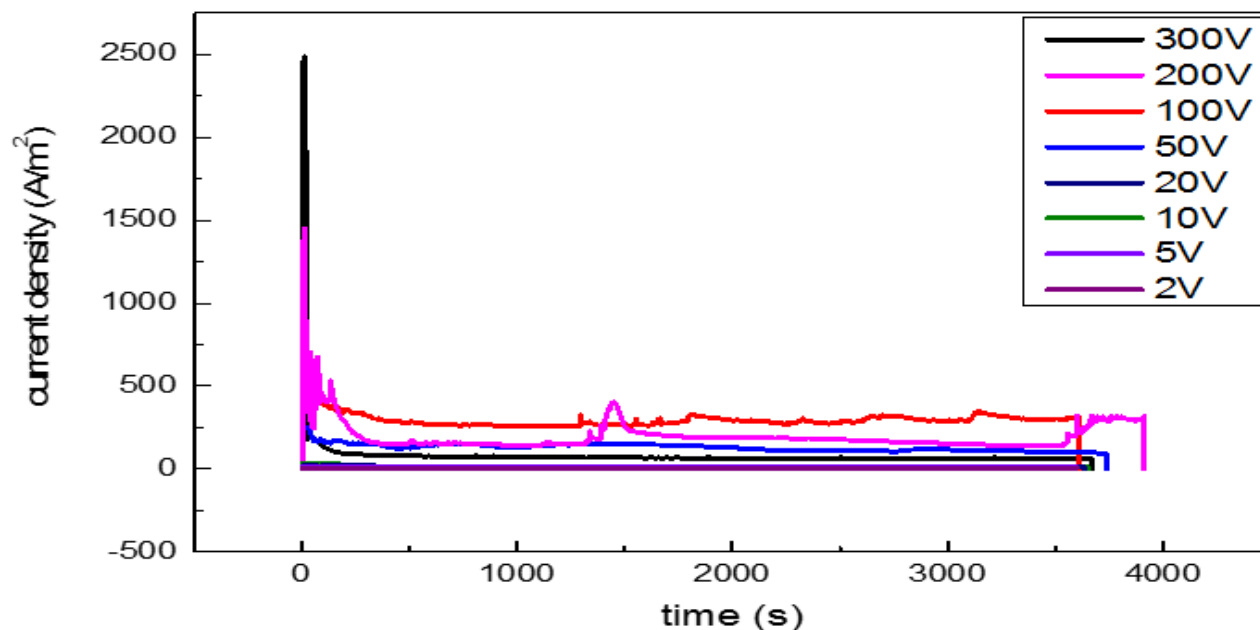


- ✓ The hydrogen embrittlement sensitivity increased when the interference voltage between **-50~-80V**. When the interference voltage is lower than **-100V**, the sensitivity of HE stays at a relatively stable level.
- ✓ When the interference voltage between **-50~-80V**, x80 sample is in **brittle zone**. When the interference voltage is shift to **-100V**, the brittleness risk reduced.
- ✓ The above phenomenon was related to the **rapid increase of solution temperature** caused by high voltage interfere, and the excessive temperature caused the change of system resistance and accelerated the escape of H_2 .



Results and discussion--Anode interference

2.2.1 High Voltage DC Interference Test in Soil

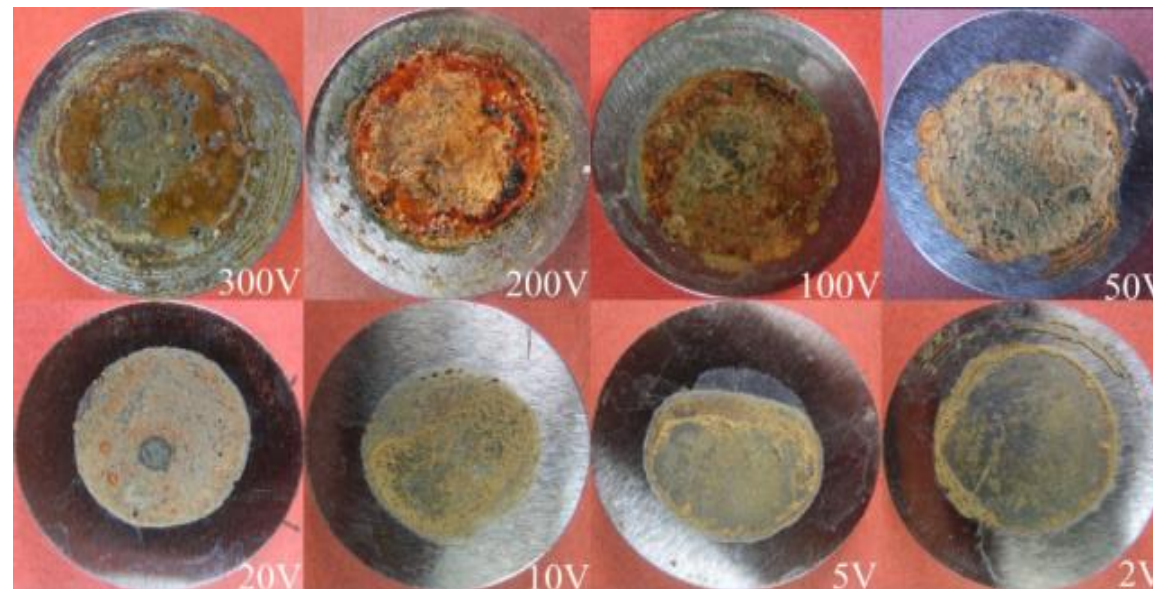
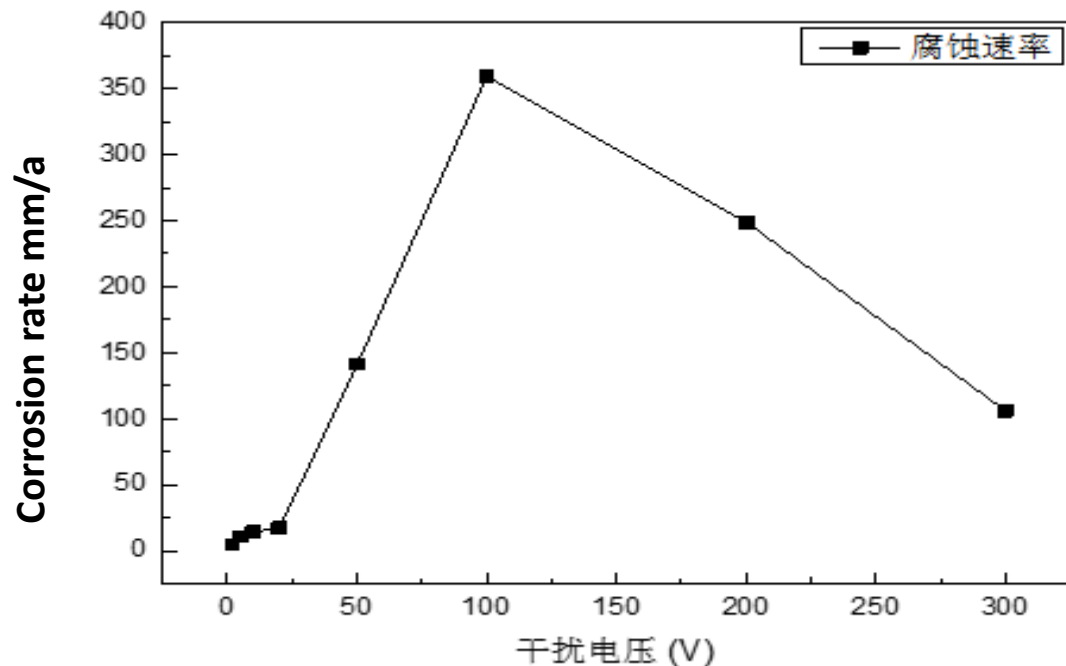


- ✓ When the interference voltage is high (above 50V), the interference current density changes greatly with time.
- ✓ High voltage direct current interference energy is large, which results in the temperature of soil rise obviously.



Results and discussion--Anode interference

2.2.2 Corrosion Rate of High Voltage DC Interference

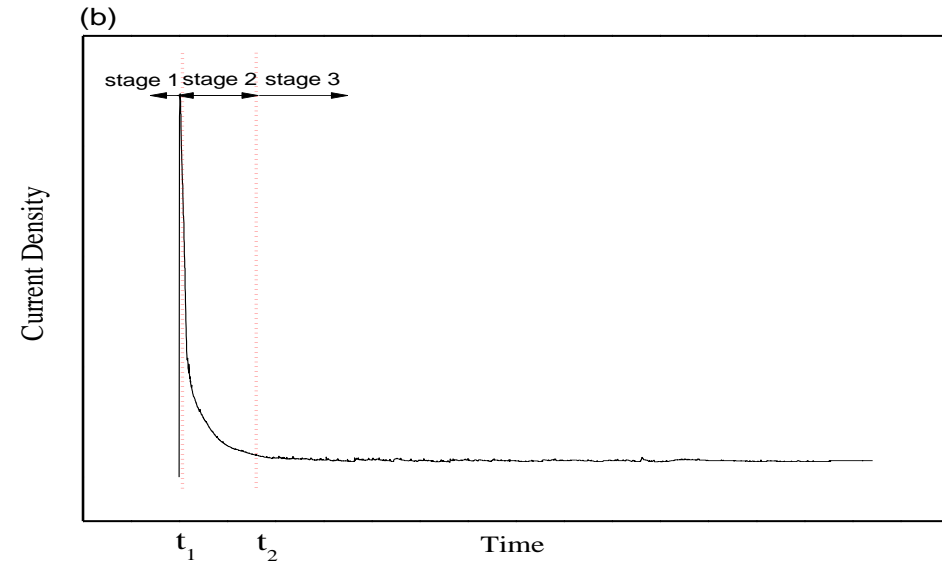
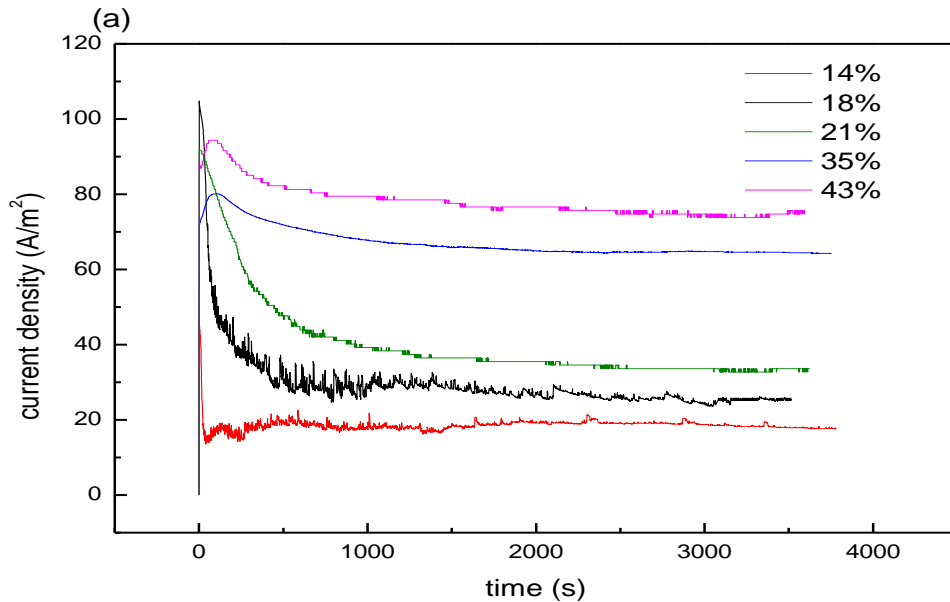


- ✓ The corrosion rate increases at first and then decreases with the interference potential rising. The maximum value is 0.04mm/h when the interference potential is 100V. Corrosion product was iron oxide.



结果与讨论 Results and discussion--Anode interference

2.2.3 Effects of different soil moisture content on the pipeline corrosion

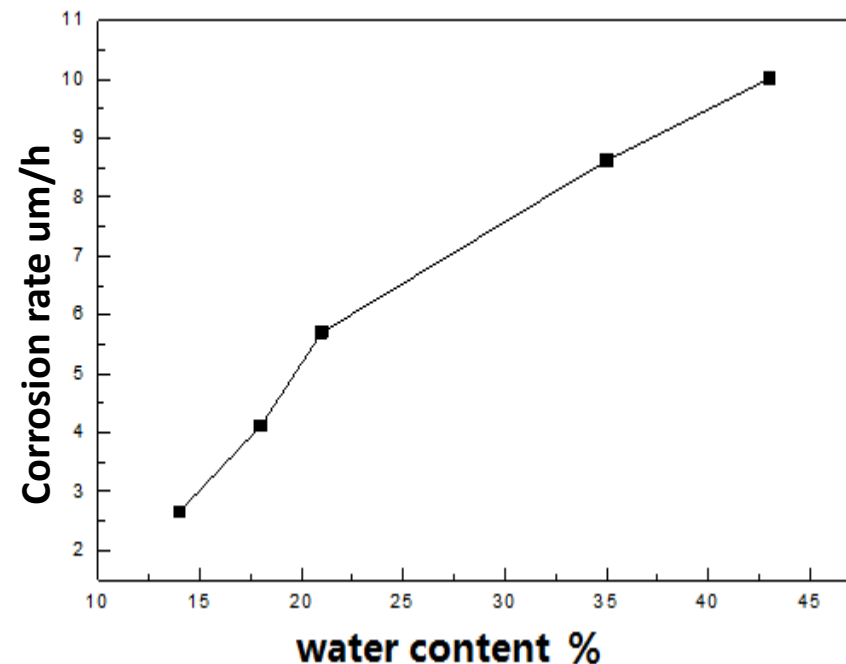
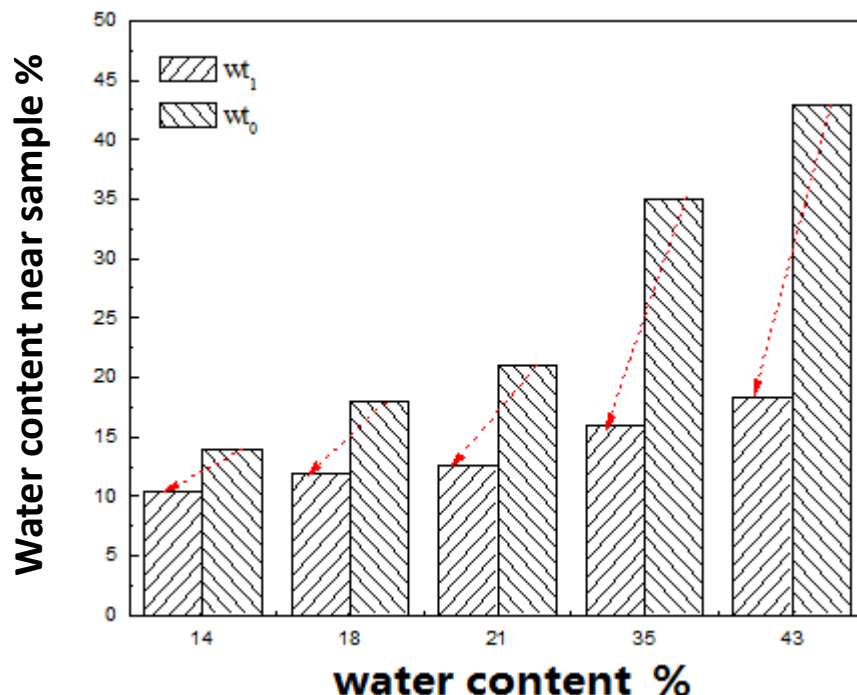


- ✓ The current density goes up with the increase of moisture content.
- ✓ The current density presents a typical three-stage characteristic when the moisture content between 14~21%, but when the moisture content under the 35~43%, the change is not obviously cause the current density is large.



Results and discussion--Anode interference

2.2.3 Effects of different soil moisture content on the pipeline corrosion



- ✓ After interference the water content wt₁ was **dropped** to wt₀ significantly, and the higher the original water content was, the more obvious the decrease was.
- ✓ The higher the moisture content of the environmental medium, the larger the decrease of the soil moisture content near the surface of the sample after interference.
- ✓ With the increase of **moisture content**, the **corrosion rate increases** gradually.



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Conclusions

- The damage caused by **HVDC interference** with hydrogen is mainly reflected in the decrease of **plastic property** of the material, and its tensile strength has no significant effect.
- The **current density/voltage** is the most important factor that affects the brittleness of fracture.
- When the current density is **$\geq 10\text{mA/cm}^2$ (-15v)**, hydrogen damage has occurred. When the current density is **$> 20\text{mA/cm}^2$** , I_{HE} is greater than **35%**, which has entered the fracture zone.
- When the interference voltage is between **-50~ -80V**, the I_{HE} of X80 is greater than **30%**, which belongs to extreme hydrogen damage and has a high risk of brittle cracking. As the voltage moves below -100V, the hydrogen embrittlement sensitivity decreased.
- The corrosion rate goes up firstly and then decreased with the interference potential rising. The maximum value was **under 100V interference**.
- The corrosion of pipeline in soil is serious when the interference voltage is **above 50V**.



Conclusions

Although there are no report of pipeline steel SCC failure in China, based on the failure cases of pipeline SCC in the world, as well as our research results, further SCC research and prevention play an indispensable role in ensuring the long-term safety operation of pipelines.



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