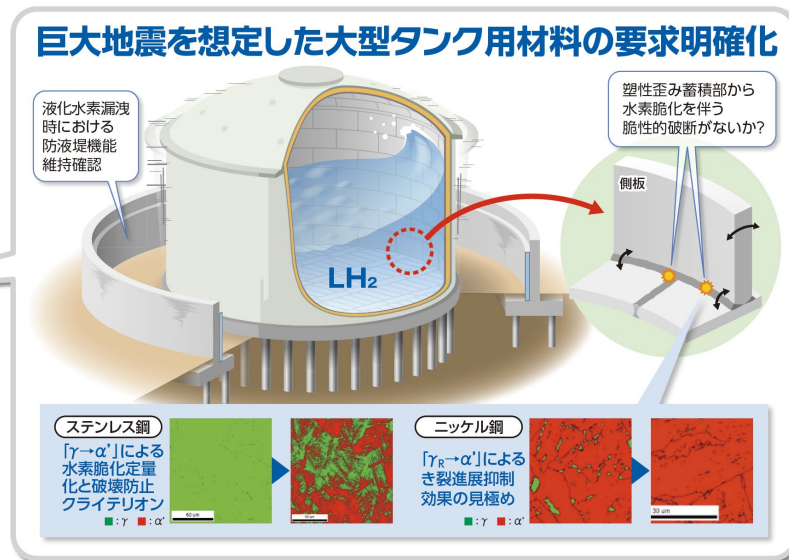
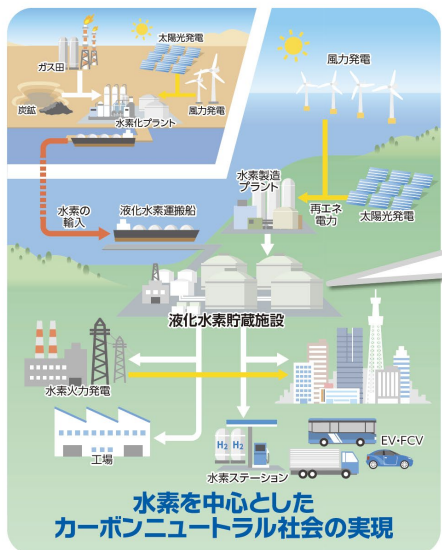


NEDO水素・燃料電池成果報告会2024

発表No.B1-8

競争的な水素サプライチェーン構築に向けた技術開発事業／大規模水素サプライチェーンの構築に係る技術開発／
大型液化水素貯槽実現に向けた極低温・水素環境下材料信頼性評価確立および社会受容のための実大試験

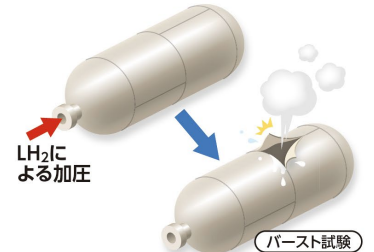


技術基準を作る

世界に先駆けた安全性を確保できる材料評価基盤の確立を目指す。



実大試験にて破壊限界を把握し安全裕度を検証

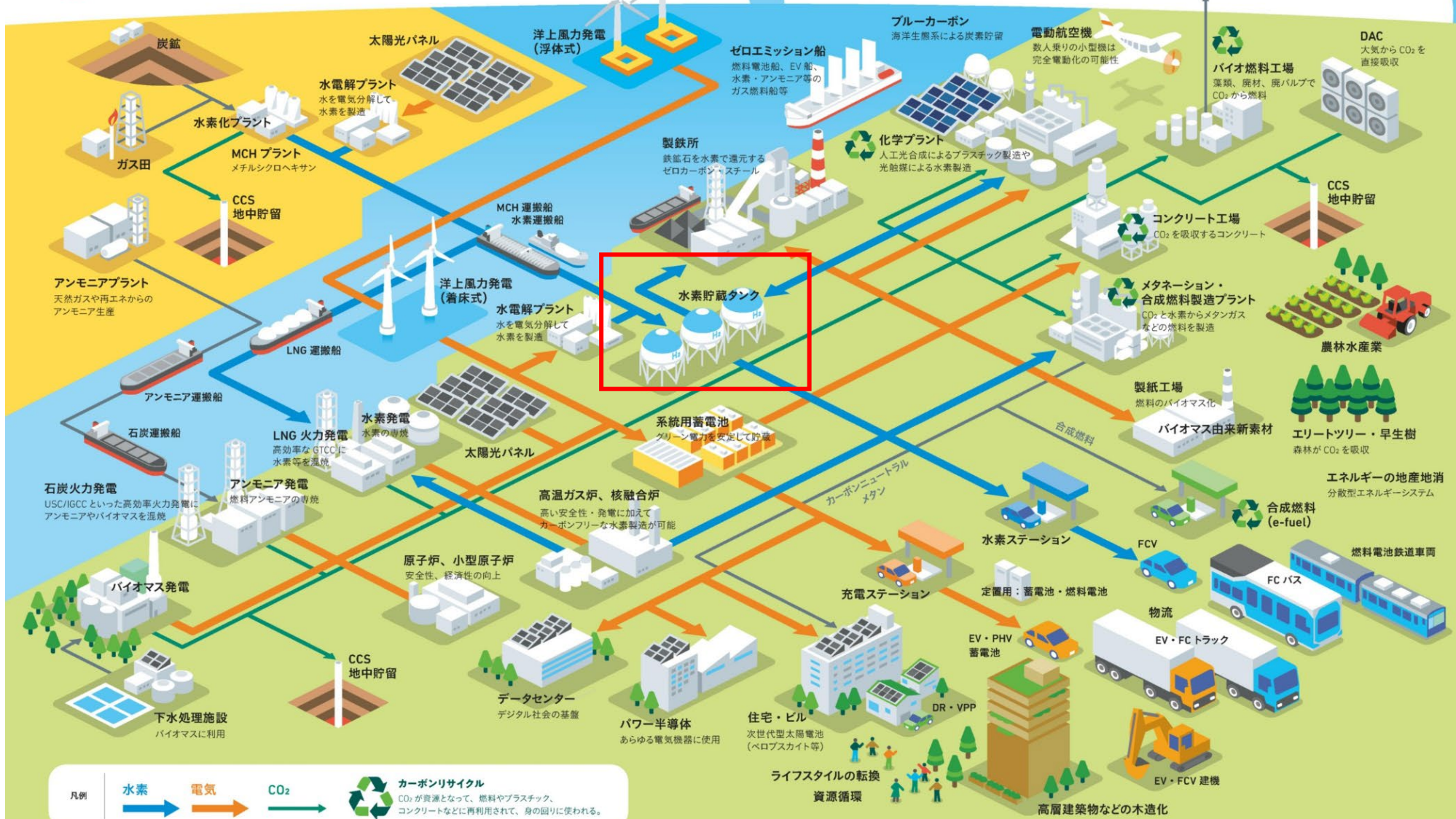


国立大学法人 東京大学
発表日 7月18日

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国立大学法人 東京大学
(kawabata@fract.t.u-tokyo.ac.jp、
03-5841-6517)

カーボンニュートラルの産業イメージ

電気はすべて脱炭素化し、産業部門の電化を進める
 水素は、発電・産業・運輸など幅広く活用されるキーテクノロジー
 CO₂は回収し、カーボンリサイクルや地中貯留 (CCS) へ



凡例
 水素 → 電気 → CO₂ →
 カーボンリサイクル
 CO₂が資源となって、燃料やプラスチック、コンクリートなどに再利用されて、身の回りに使われる。

事業概要

1. 期間

開始 : (西暦) 2023年4月
終了 : (西暦) 2026年3月

2. 最終目標

世界に先駆けて、水素発電の本格的な導入と大規模な水素サプライチェーンを構築することで、水素源の権益や輸送・貯蔵関連技術の特許等の多くを掌握し、産業競争力の強化とエネルギーセキュリティの向上に貢献すること

3. 成果・進捗概要

材料へ要求すべき評価基準を合理的に設定するために貯槽の巨大地震時解析を実施しているが、特に底板の滑り挙動について2022年度の解析結果について不確実性があったため、その疑念を払しょくすべく極めて丁寧なプロセスを経た動的解析を実施し、2022Fy解析の正当性をおよそ支持できる結果を得た。これにより、材料に必要な定量的クライテリオン限界J値やそれを換算した要求シャルピー衝撃値などを今後算出できる。さらに水素脆化特性について系統的なSSRT試験を実施し、貯槽中の地震発生による塑性変形が水素脆化（-75℃にて最も活性化する）を促進することを初めて知見した。また、過去のLNG貯槽の例を考慮しても、それだけでは大規模実用にはまだ材料評価として不足である。社会受容のためには小型試験結果と理論の組み合わせのみならず、貯槽構造の一部を切り取ったような実大部材試験を実施する必要がある。同事業ではこの実大評価の足掛かりとするべく、3つの実大試験を実施する。8000ton試験機を用いた広幅引張試験（LHeによる20K再現）、最過酷部を模擬するL字試験（LHeによる20K再現）、バースト試験（実液化水素使用）である。このうち2023年度には8000ton試験およびL型試験を実施した。いずれも候補材料の適性を指示する結果を得た。

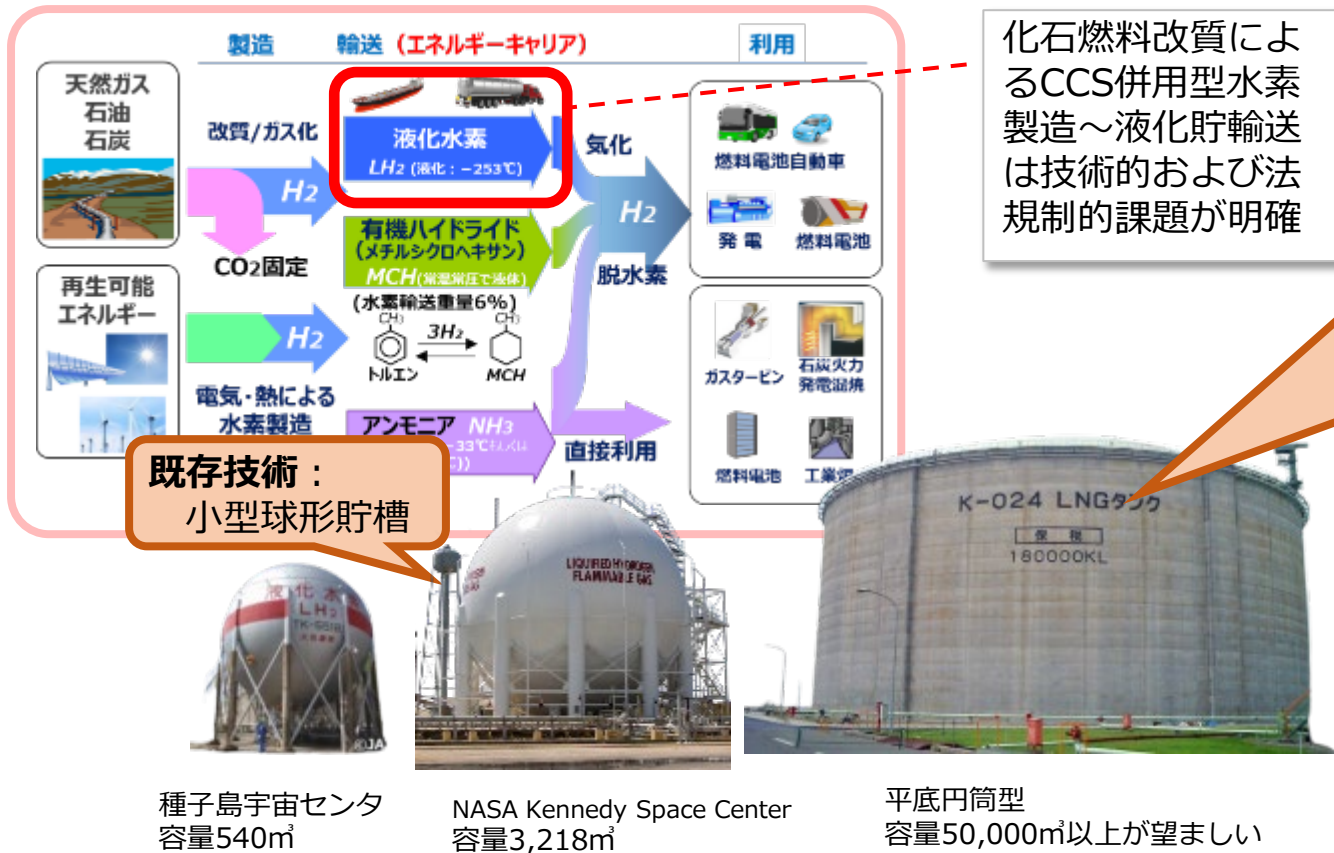
1. 事業の位置付け・必要性

「水素利用等先導研究開発事業」基本計画に記載されているように、我が国のエネルギー政策は2017年12月、2023年6月に取りまとめられた『水素基本戦略』に基づき、エネルギー安全保障と温暖化対策の切り札として水素を取り扱っている。また、本研究テーマは「再生可能エネルギーからの高効率低コスト水素製造技術、水素の長距離輸送、長時間貯蔵を容易にするためのエネルギーキャリア技術及び大規模水素利用技術の先導的な研究開発に主として取り組む」とする本事業の精神に合致したものである。本研究テーマの最終的なゴールは以下の2点である。

- ✓ これまでWE-NET事業などで提案されてきた有望な材料（母材・溶接部）を用い、平底円筒型大型貯槽が最もシビアな状態である大規模地震に見舞われた後を想定した評価試験を多面的に実施することにより、同状況でも強度および耐破壊特性の面で健全性を損なわないことを評価する手法およびクライテリオンを開発すること
- ✓ さらに社会受容の面で不可欠な貯槽構造物一部の実大模型を用いた液化水素温度での評価試験方法は世界に存在しないことから、これを実現し、候補材の安全性を確認すること。

1. 研究開発計画

研究目的の概観図



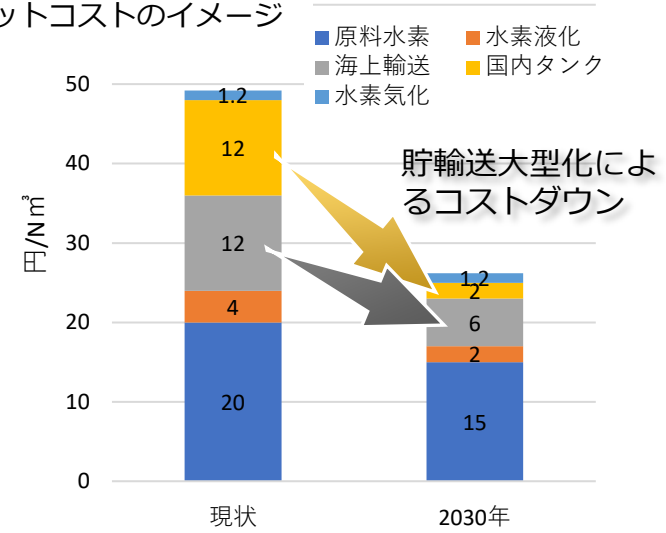
既存技術：
小型球形貯槽



種子島宇宙センタ 容量540m³ NASA Kennedy Space Center 容量3,218m³ 平底円筒型 容量50,000m³以上が望ましい

本研究狙い：大型平底円筒型液化水素貯槽はこれまで概念設計・材料基礎特性評価がそれぞれ個別に行われただけであり、設計面から真に材料に要求する特性は不明である。本研究により直ちに**社会実装できる材料信頼性評価手法を開発し、評価設備を整備する。最終的に規制当局の判断を助ける技術データを蓄積し、法規制の基礎となる技術基準を整備する。**

化石燃料（豪州褐炭）液化水素ルートにおけるターゲットコストのイメージ

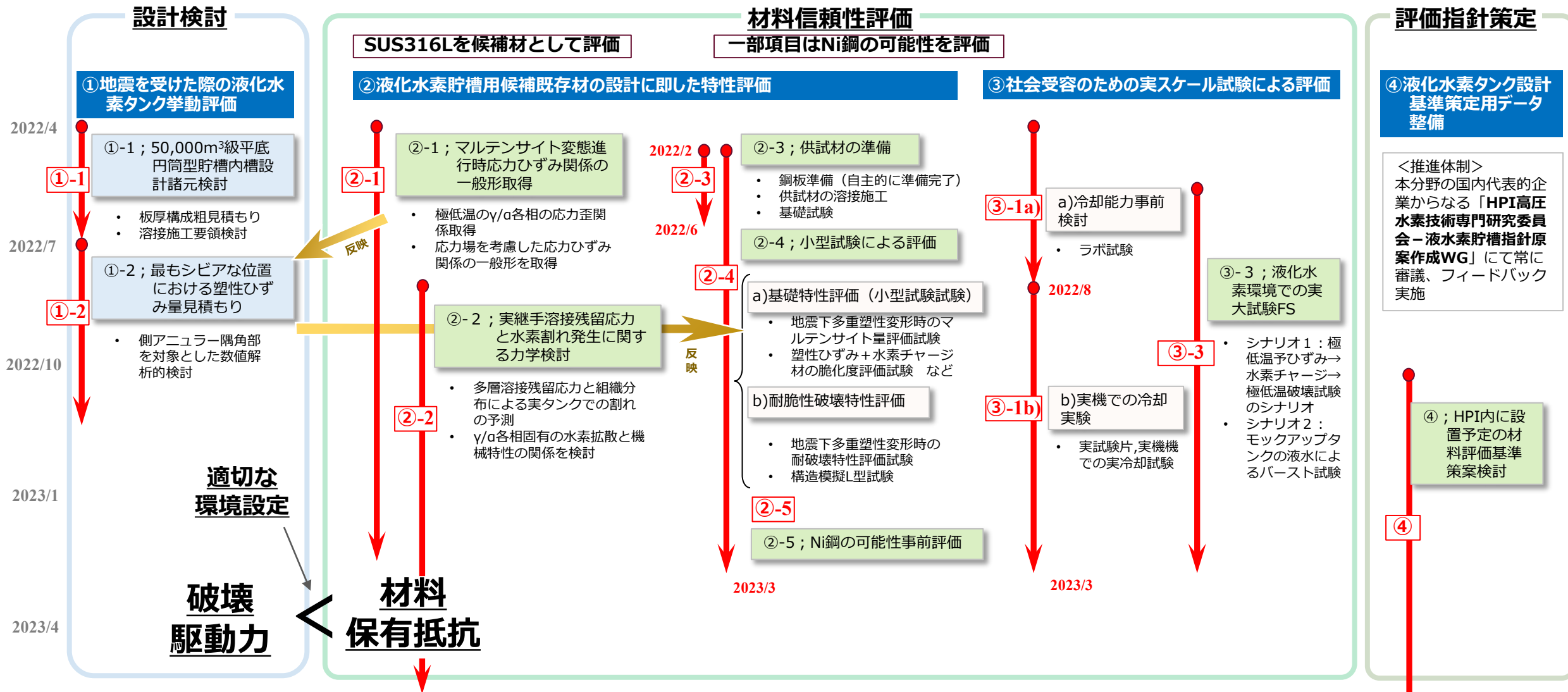


目標サービスプライス30円/Nm³を達成するためには、輸送コストの低減が必須であり、同時に国内の受け入れタンクも大型化が不可欠である。液化水素球形タンク大型化は2000~3000m³が限界。LNGタンクで実績のある平底円筒貯槽の新規設計が喫緊の課題である。

2. 研究開発マネジメントについて

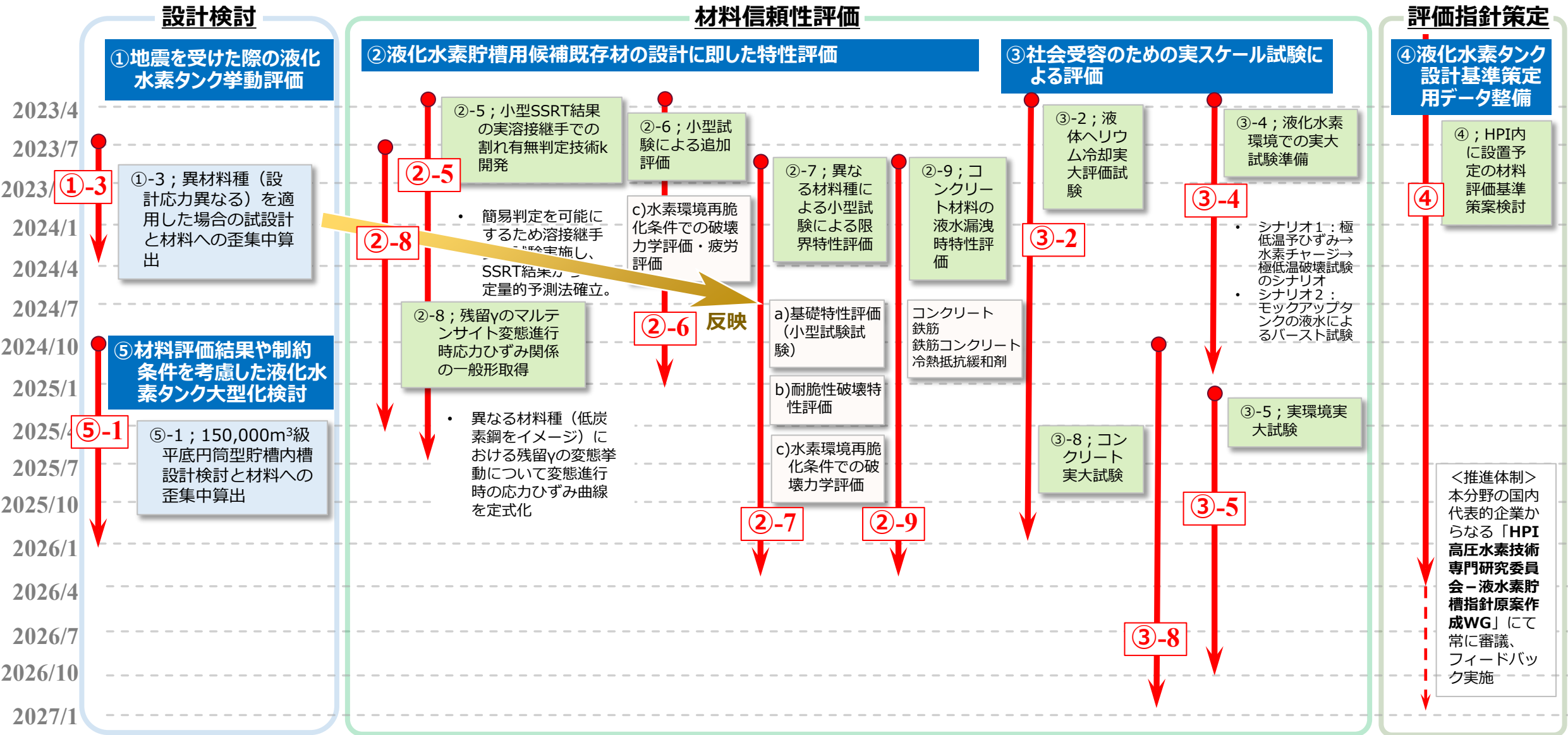
2022Fy事業における研究成果

★本事業の目的；大型液化水素貯槽を社会実装できる材料信頼性評価設備を整備するとともに、評価手法を開発し指標を提案する。最終的に法規制の基礎となる技術基準策定に資するデータを提供する



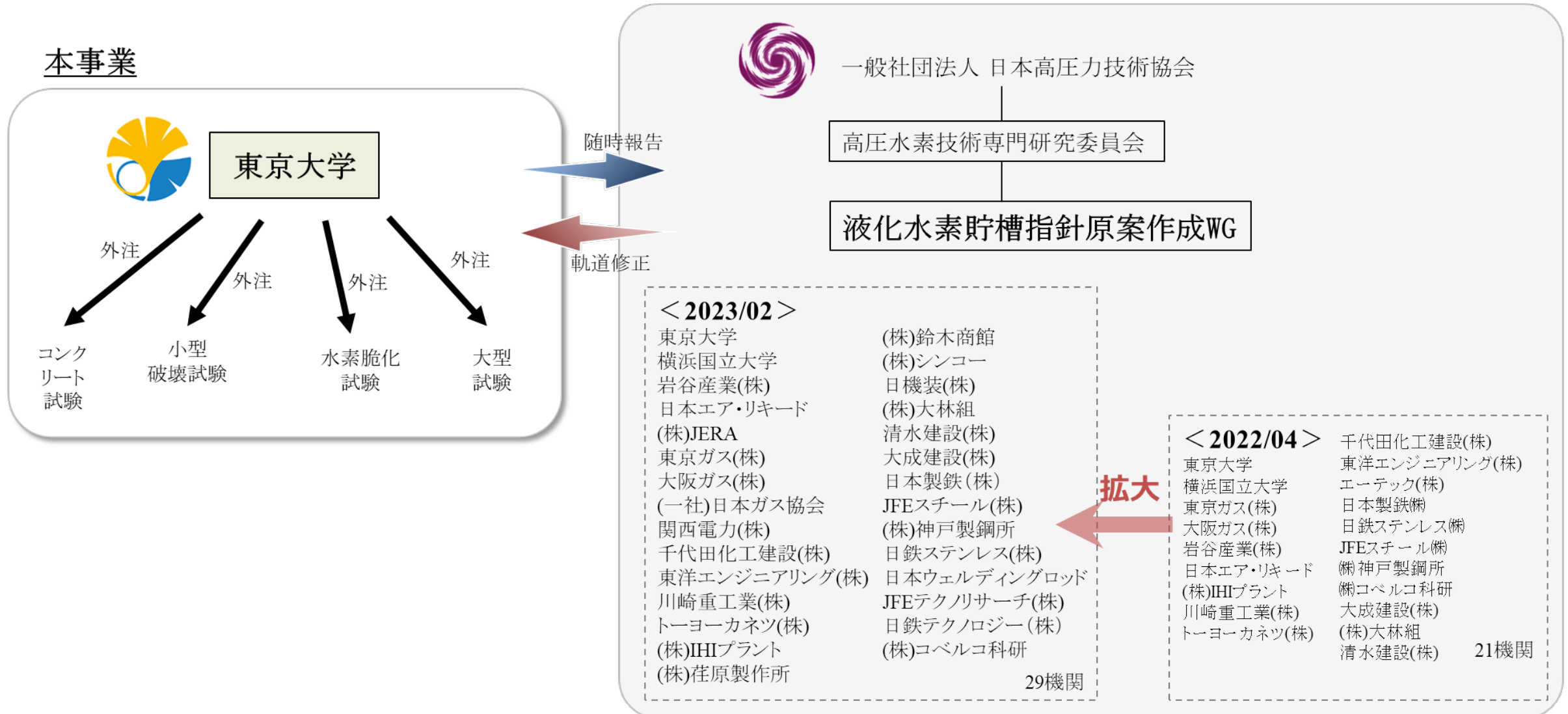
2. 研究開発マネジメントについて

2023年度以降の研究計画（4か年計画）



2. 研究開発マネジメントについて

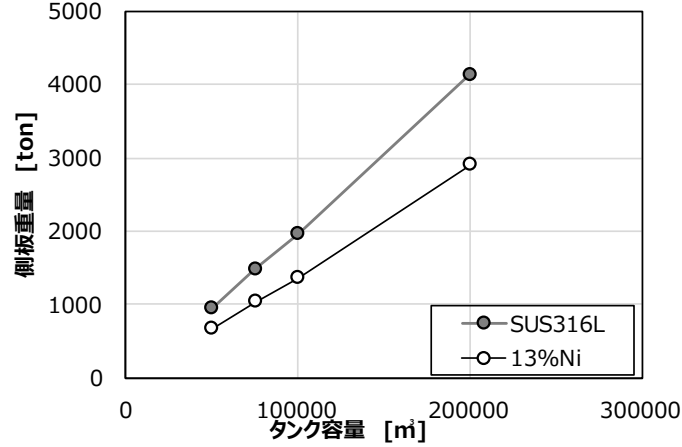
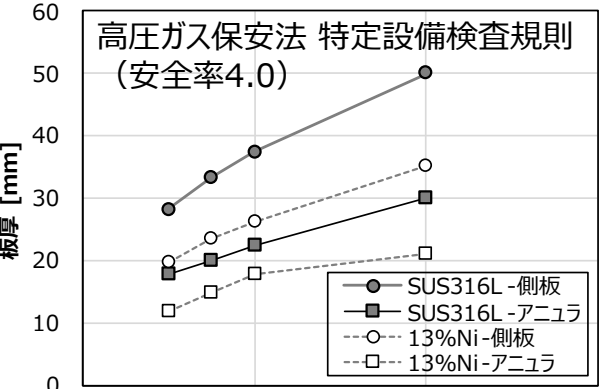
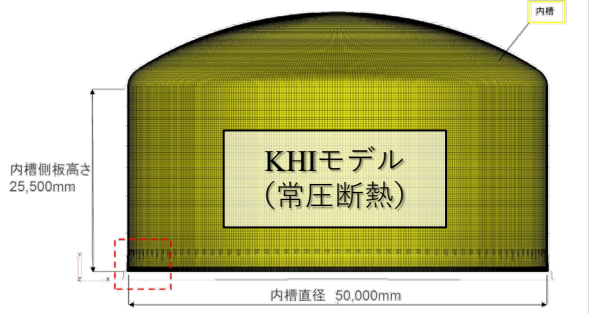
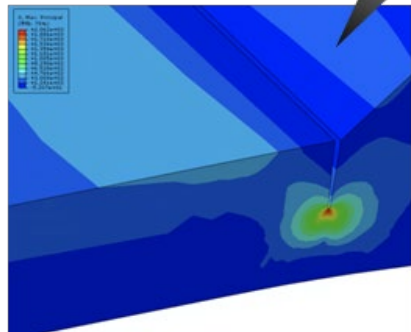
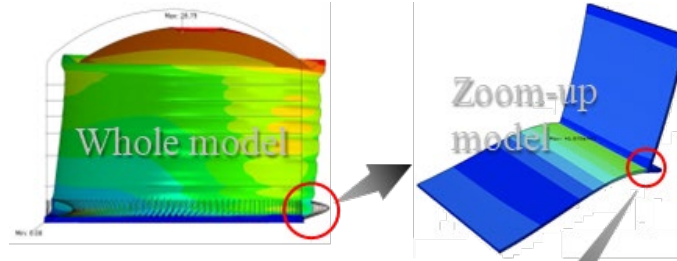
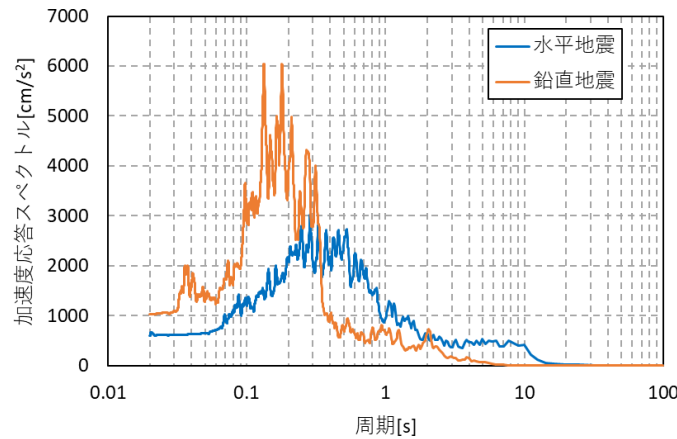
研究開発の実施体制



3. 研究開発成果について

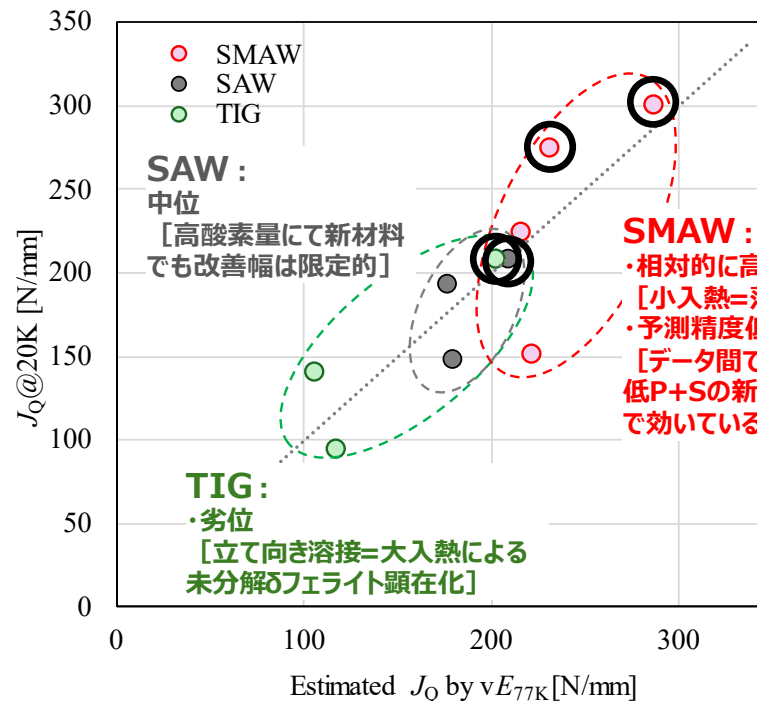
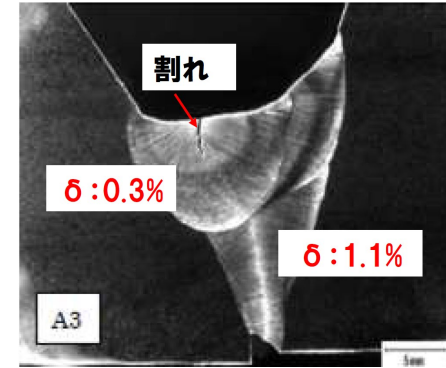
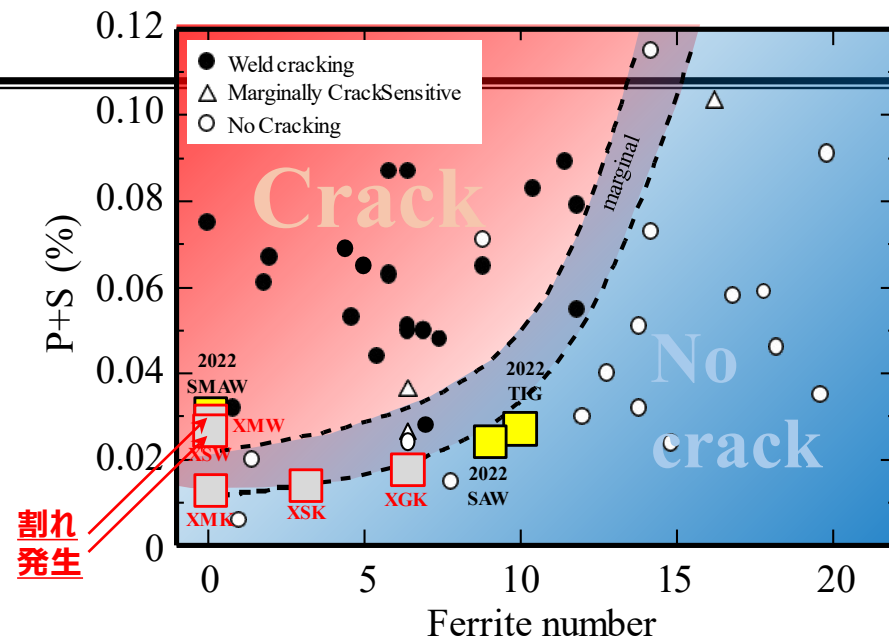
事業項目	成果概要
①-1 50,000m ³ 級 平底円筒型貯 槽内槽設計諸 元検討	2022Fy事業では、最下段×ア ニユール部が最も過酷な応力および 歪がもたらされることが判ったが適 切な底板摩擦係数が不明であった。 この疑問点を解消するべく、 動的 解析 に着手。鉛直波はサイトスペ シフィック地震動、水平は適合波 に合致するように地表面波形を バーチャルに作成し計算。 タンク滑 り量は最大で15mmであり、塑性 変形範囲は限定的 であることが 判った。
①-3 異材料種（設 計応力異な る）を適用し た場合の試設 計	第二の候補材として炭素鋼系の 13%Ni鋼を設定した。炭素鋼の 長所は安価である点と設計応力が 高い点である。高圧ガス保安法 特定設備検査規則による試設計 実施。今後のタンク大型化に伴い、 SUS316Lでは20万m³で50mm に到達するのに対し、13%Niでは さらなる大型化余地が大きい ことが 改めて示された。

地震波：防災科学技術研究所のK-NET 観測点 KNG001 (K-NET 川崎) の対象地点



3. 研究開発成果について

事業項目	成果概要
②-5 小型 SSRT 結果の実溶接継手での割れ有無判定技術開発	ステンレス溶接部の高温割れのこれまでの研究結果により、不純物元素や δ フェライト量の低減が効果があることが示されてきた。本事業で実施した継手もこれまでのP+S, FNによる整理結果と整合することを確認した。
②-6 小型試験による追加評価	2022Fy時点で市販溶接金属の靱性裕度は大きくなかったが、試作材開発により高位にシフト、高温割れ特性も含め、P, S, FNにて概ね制御できる可能性が示された。またシャルピー衝撃値(77K)からの換算方法についても開発を進めた。



黒丸は試作溶接材料

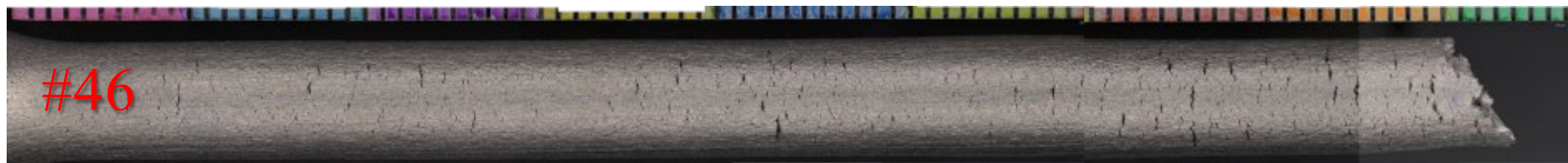
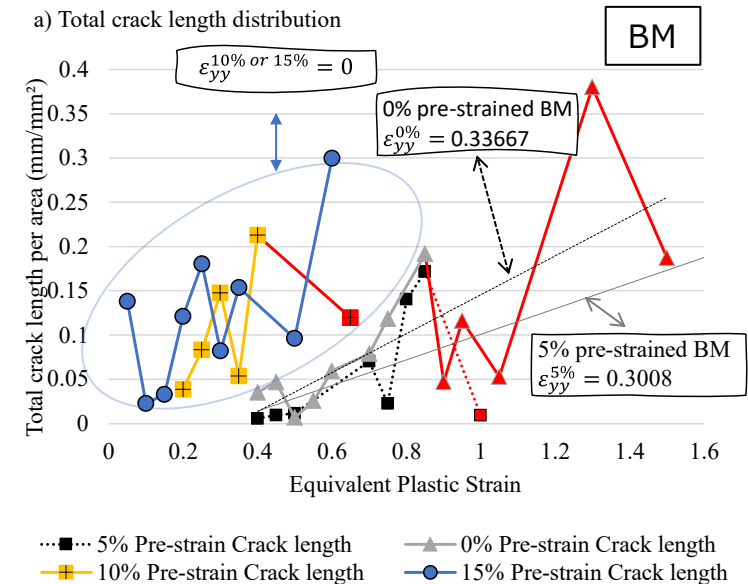
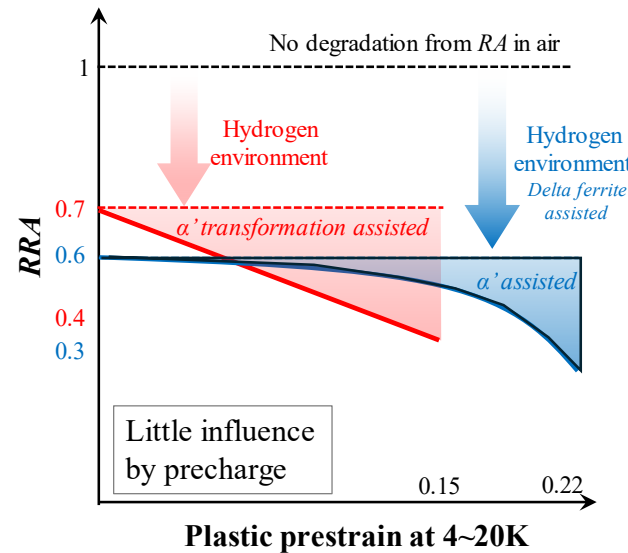
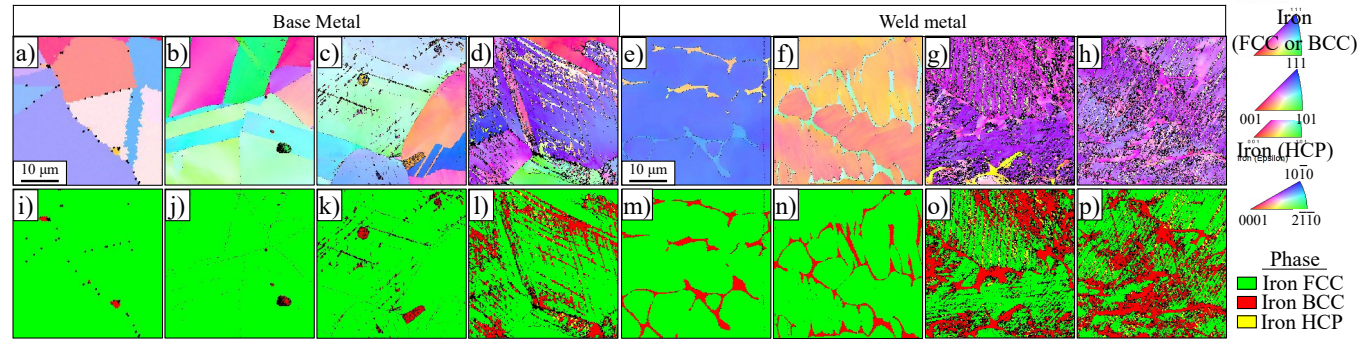
SMAW :
 ・相対的に高位
 [小入熱=薄積層による δ フェライト分解促進]
 ・予測精度低、バラツキ大
 [データ間でMd30およびP,S変動大.低Md30, 低P+Sの新KSL材はかなり安定.FN低減もどこまで効いているか不明]

TIG :
 ・劣位
 [立て向き溶接=大入熱による未分解 δ フェライト顕在化]

提言：
 低Md30は一つの方針になるのではないか。

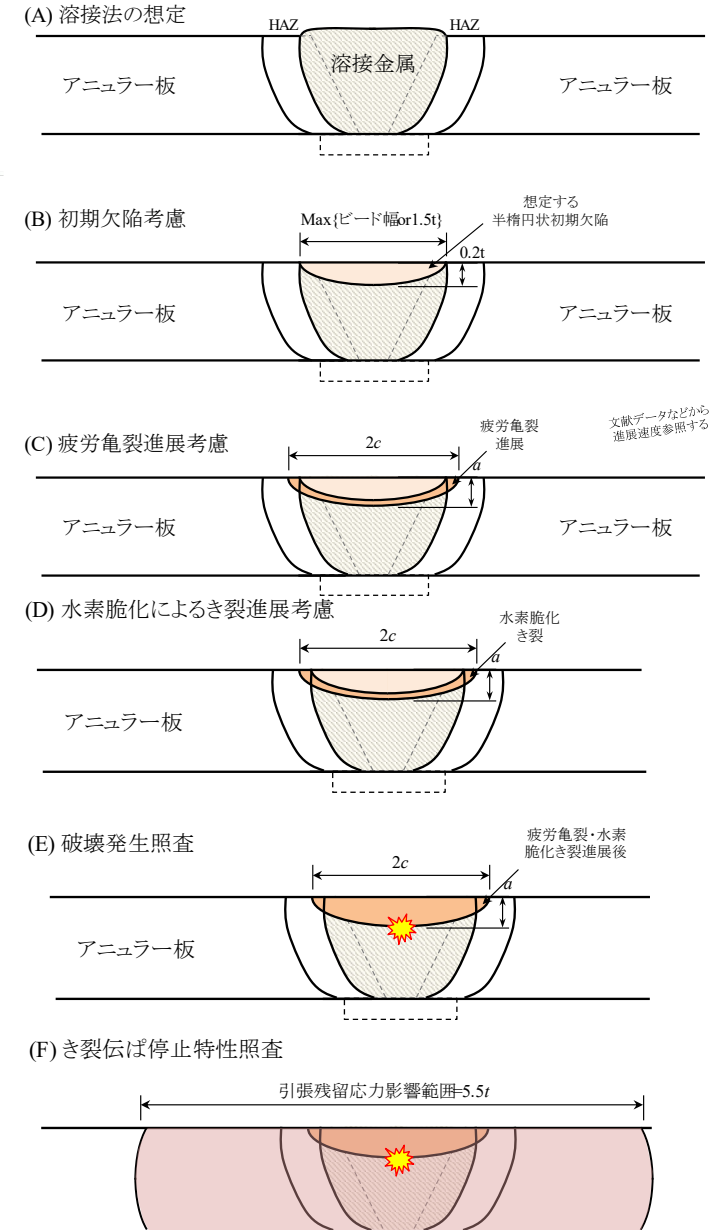
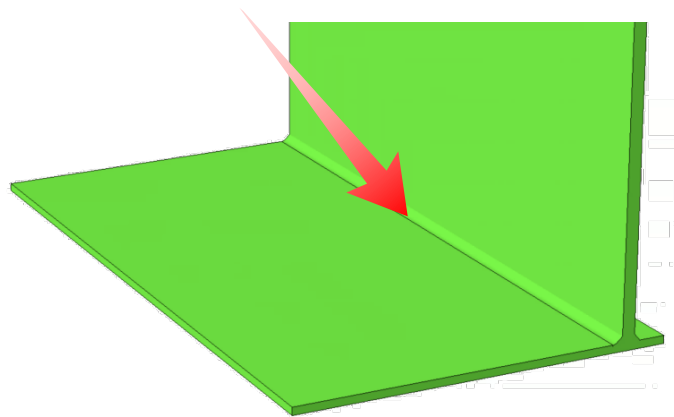
3. 研究開発成果について

事業項目	成果概要
②-6 小型試験による追加評価 (水素脆化)	母材、TIG溶接金属のSSRT試験をRRAで整理すると、4Kによる予歪付与量増加に伴い、特性は低下する。母材試験において特にマルテンサイト変態が増加する10%以上の予歪量においては変形初期から表面き裂が増加した。
②-6 小型試験による追加評価 (新水素脆化評価法開発)	実際の貯槽が水素脆化でき裂進展する可能性があるのは、内容液が枯渇しタンク全体が温度上昇する入れ替え時である。この時の水素脆化挙動は塑性変形量は少なく、長時間定荷重に晒されたときの亀裂進展である。その状況を再現できる試験機を製作しトライアル試験実施した。



3. 研究開発成果について

事業項目	成果概要
②-6 破壊シナリオの構築	レベル2地震動を想定し最も過酷な部位に最安全側の初期欠陥を想定した場合に破壊が起こらない。また万が一き裂が発生進展し、リークしても全体崩壊が起こらないことを保証する (LBB)



2022Fy構造解析での最大駆動力を採用し疲労き裂進展、水素脆化による進展量(現状見積り困難)は小さいとして、 $c=1.5t$, $a=0.2t$ の半楕円欠陥がアニュラー相互継手溶接金属かつ隅角部Toe部に存在するとして発生駆動力を試計算。(ただし駆動力は2023Fy動的解析により今後下方修正予定)

WES2805

$\delta = 0.06\text{mm}$
 $J=116\text{ N/mm}$

API579 /ASME-FFS

$\delta = 0.03\text{mm}$
 $J=56\text{ N/mm}$

BS7910

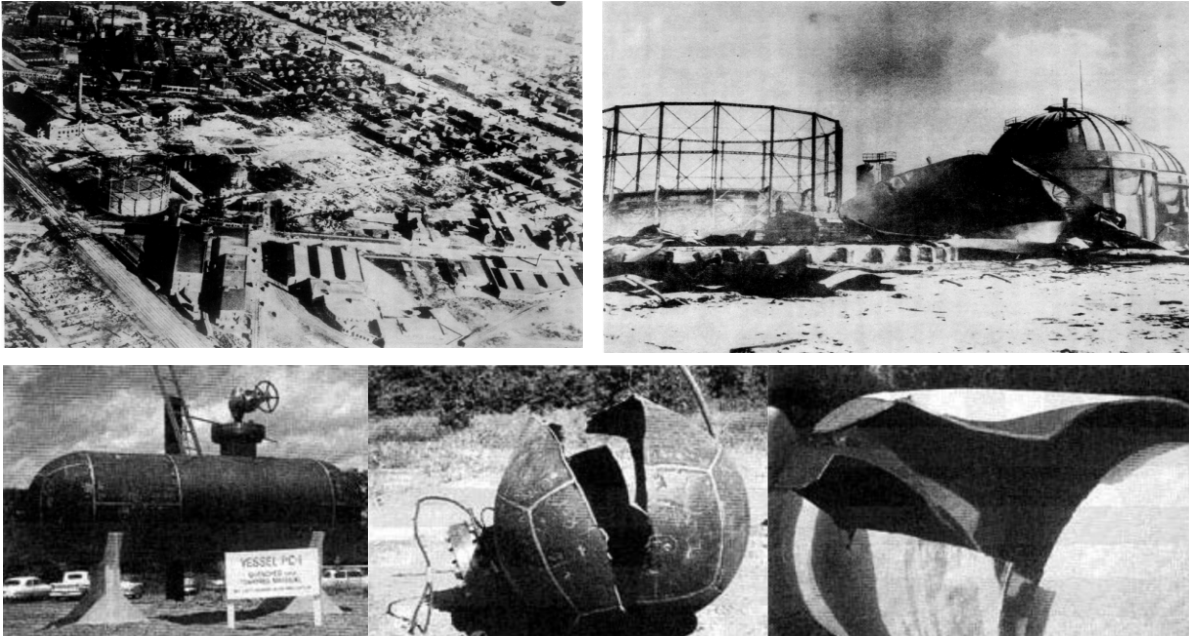
$\delta = 0.07\text{mm}$
 $J=135\text{ N/mm}$

※万が一不安定き裂が発生しても延性き裂は母材でアレスト可能か

3. 研究開発成果について

③ 社会受容のための実スケール試験による評価の意義

- ②の事業終了後には材料指針策定本格着手可能となる。
- ただし、**社会受容のために**、実大大型試験の手法を確立し、日本に一つで良いので、液化水素温度以下で評価可能な**大型試験を設置しておく必要がある**
- LNGタンクの高い技術レベルは悲惨な事故の歴史により作られた。現在でも国内PJでは仕様が変わるたびにほとんどの場合実大材料性能確認試験を実施している。



LNGタンク一号機の爆発事故からその後の設置と安全性指標確立に至る道のり

LNGタンクの一号機（米国）は1944年に使用開始から半月ほどで死者120名を超す大爆発事故を起こした。（原因は材料の破壊靱性不足、選定ミス）

9%Ni鋼開発（1949年）

9%Ni鋼ASTM・ASME規格化 [要求値決定]（1952年）

“Operation cryogenics” 研究実施（1960）

米国にて **9%Ni鋼製**LNGタンク初操業（1963）

LPGタンク（カタール）で爆発事故（1977）原因は溶接不良と材料靱性不足

LNGタンクも設計見直し・ダブルインテグリティ要求へ（1979年～）

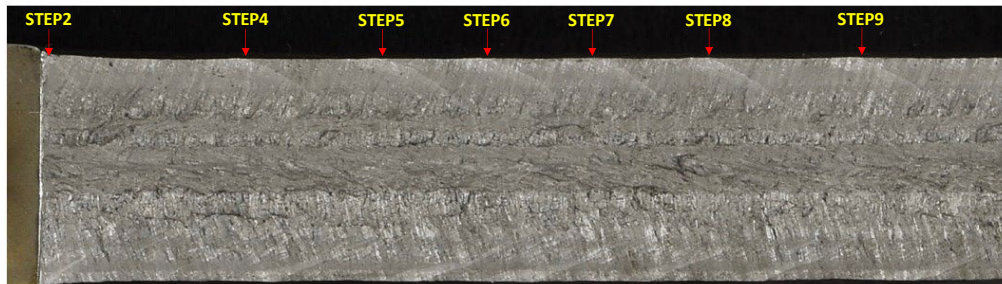
写真上：クリーブランド事故、下：Operation Cryogenicsによる大規模実大バースト試験，
Kawabata and Hirose : A Transition of Philosophies of Fracture Safety and Materials in Liquefied Natural Gas Storage Tanks, ISOPE2017.

3. 研究開発成果について

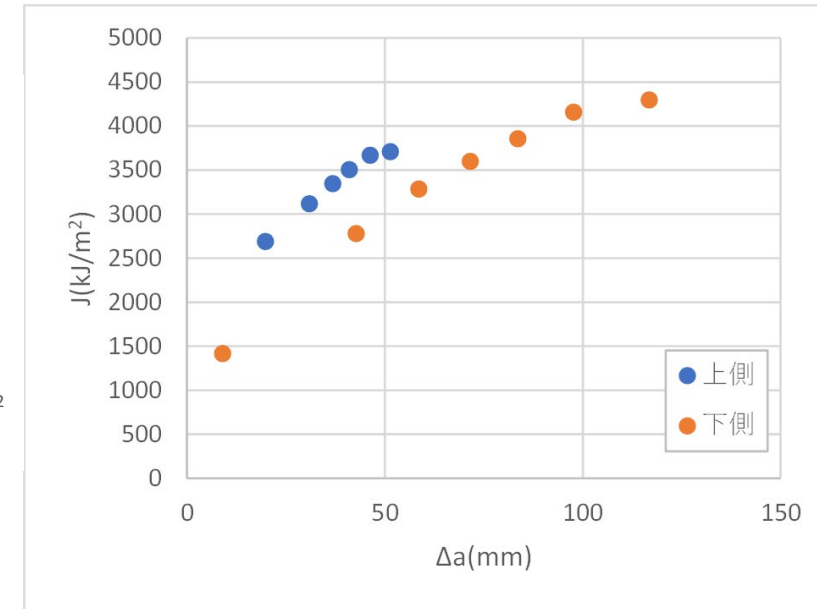
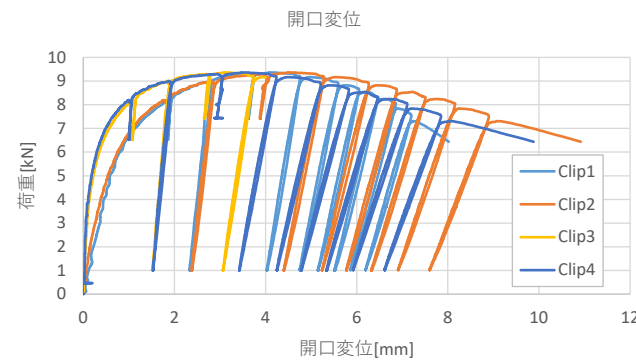
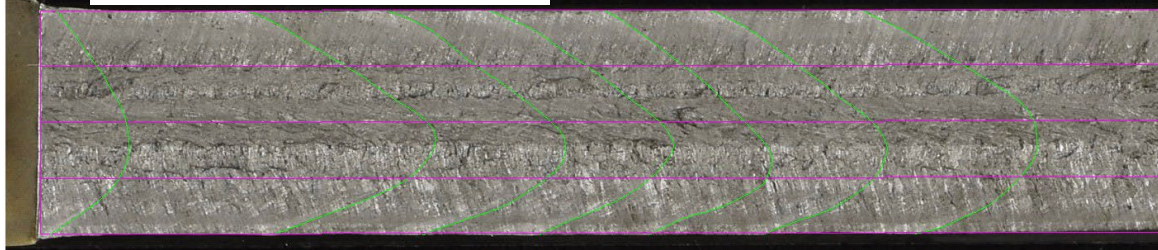
➤ 8000ton引張試験機による延性き裂抵抗評価試験

2023FyにはSUS316L溶接継手を用いて77Kによる試験を実施。試験は問題なく実施できた。

CT試験片では低い靱性値を示していたものの、広幅引張試験において十分高い J_{IC} 値を確認できた。



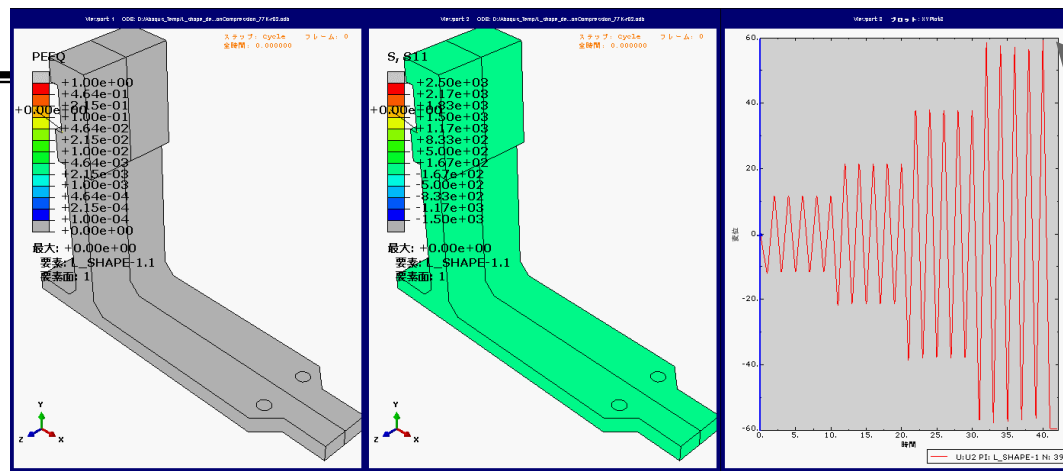
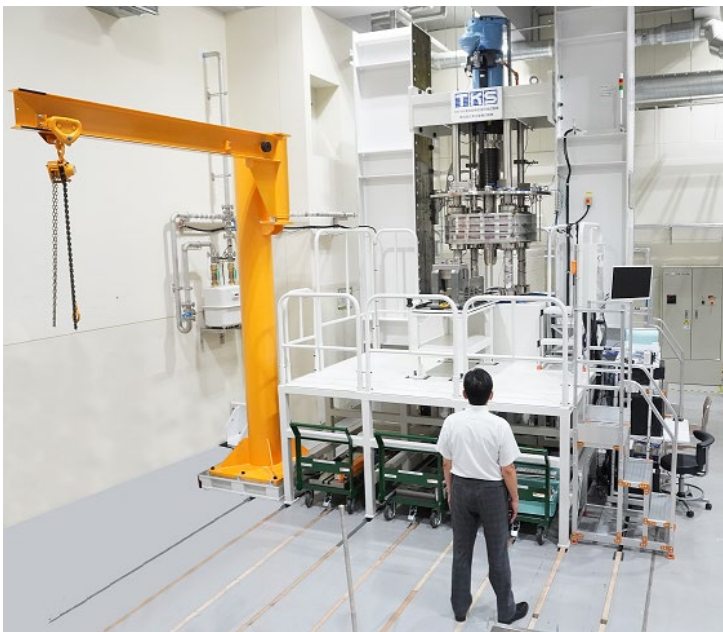
板厚表面付近の痕跡から中央部を予想して描画(黄線)
板厚を4分割(桃色)して交点までの距離をD上で計算



$J = \delta \times \sigma_y$ を用いて換算

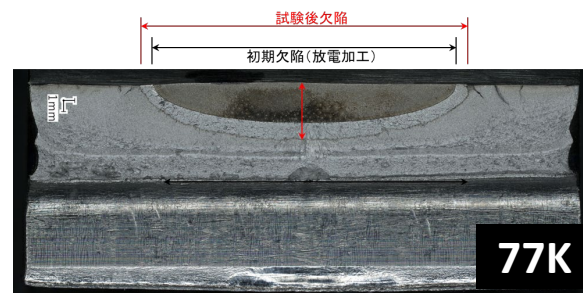
3. 研究開発成果について

L型構造要素の繰り返し負荷試験



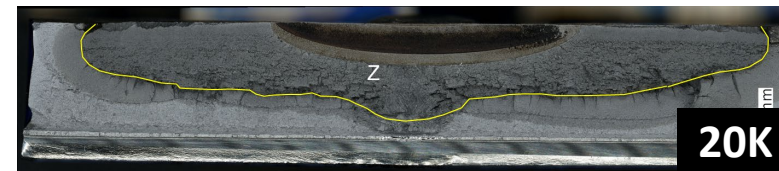
亀裂深さ変化

溶接法 1

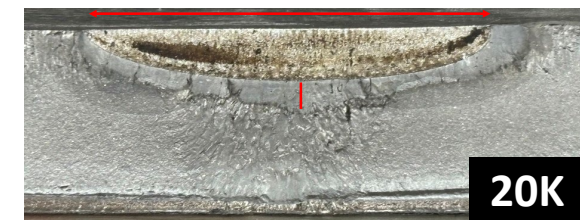


3.6mm→5.1mm

溶接法 2



5.4mm→12.5mm



3.6mm→5.3mm

世界初の実構造要素の実大曲げ試験。最終条件とした激甚振幅10回で単純にき裂伝ぱが1/10ずつ進むとすれば、1回あたりの進展量0.5mm@77K, 1.2mm@20Kと大被害にならないこと実証。今後、残留応力解析を含めさらに詳細な分析を行い、安全性を結論づける。

3. 研究開発成果について

鉄筋、PC鋼材の耐水素脆化特性評価試験

土木材料の液化水素に対する使用可否を判断する試験

試験方法：一定荷重を負荷した状態で水素ガス環境下に暴露

媒体：水素ガス

温度：常温、低温

期間：10日間の水素暴露環境下

・鉄筋
SD345 D13



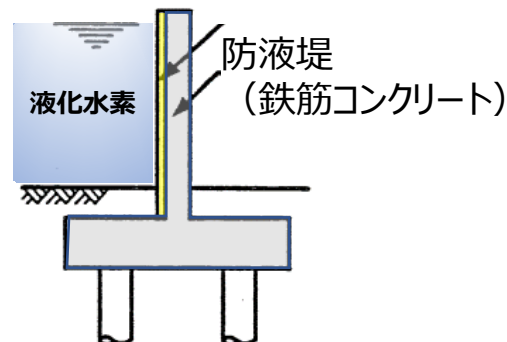
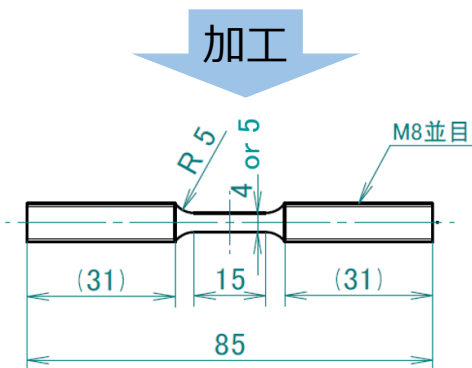
・PC鋼線
SWPR1AN 9mm



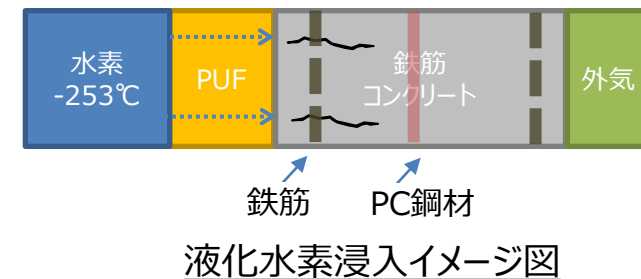
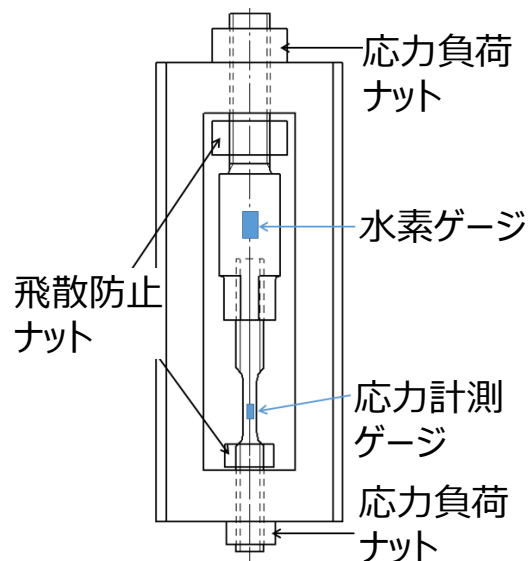
・PC鋼棒
C種 1号, 9.2mm



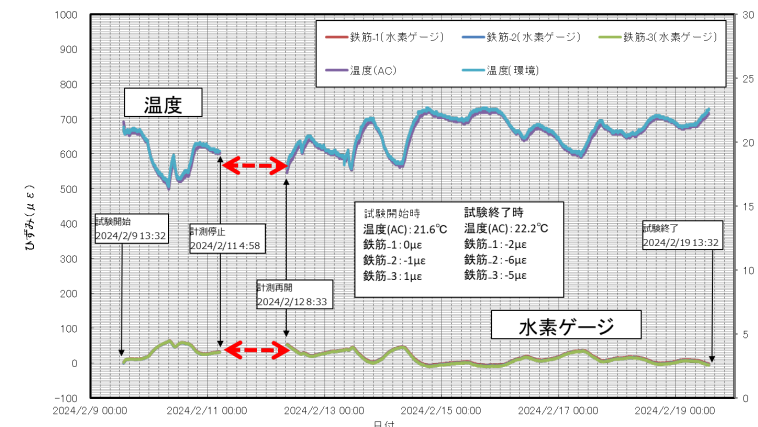
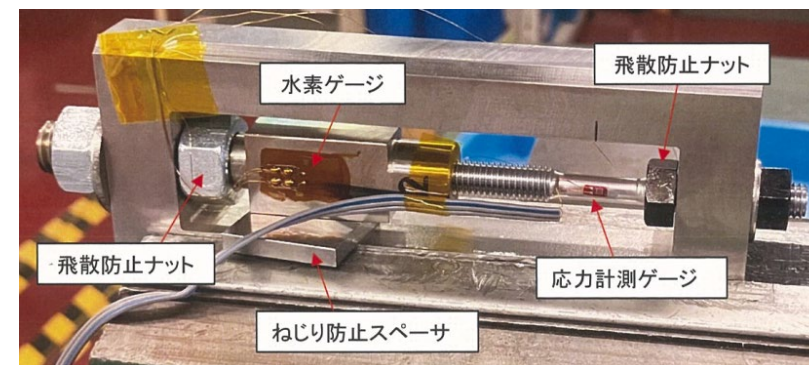
加工



金属二重殻貯槽
防液堤の構造形式例



液化水素浸入イメージ図

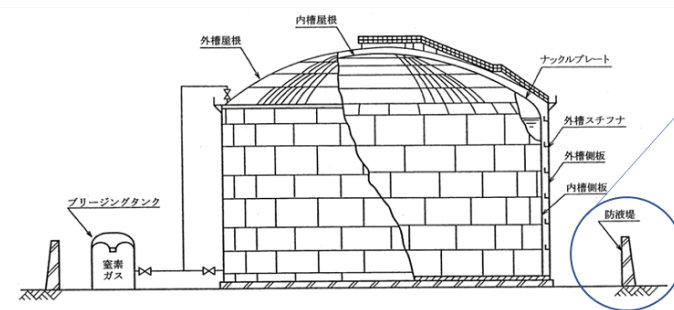
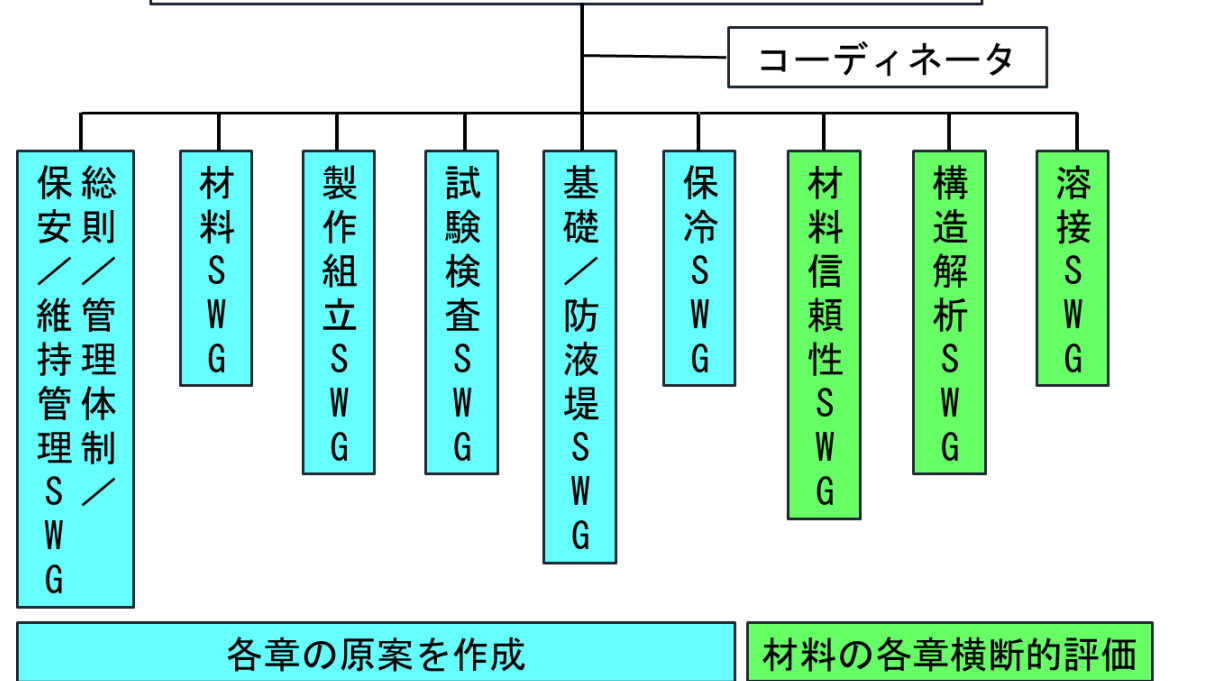


水素脆化特性評価法として定荷重引張試験を実施。
鉄筋1/2σ_{ys}、PC鋼線0.7σ_{ts}の応力負荷にて常温実施。
き裂発生、破断など観察されず良好

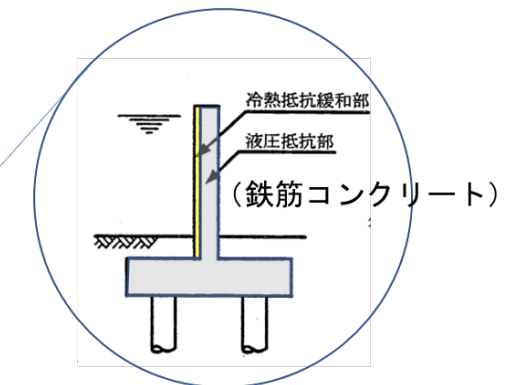
3. 研究開発成果について

事業項目	成果概要
④ 液化水素貯槽設計基準策定用データ整備	<p>作成すべき指針の原案を策定すべく、液水WG内に幾つかのサブWGを設置し、それぞれの専門家による分科会方式にて基準の在り方についてディスカッションをおこなっている。実施実績は以下の通りである。2023Fy事業の構造および材料データを常に評価しながら進めた。</p> <ul style="list-style-type: none"> • 構造解析SWG 8回 • 材料信頼性SWG 2回, • 溶接SWG 3回 • 総則SWG 2回 • 構造設計SWG 1回, • 製作組み立てSWG 3回, • 試験検査SWG 3回, • 基礎防液堤SWG 8回, • 保安SWG 5回

大型液化水素貯槽指針原案作成WG



金属二重殻貯槽の概念図



防液堤の構造形式例

事業成果の一部は国際会議にてPRする。

ISOPE2024

Effect of TRIP on Crack Opening and Closure Behavior of Austenitic Stainless Steel

Yuji Ando*, Ritsuki Morohoshi*, Shohei Uramaka*, and
*The University of Tokyo, Department of Systems
Bunkyo, Tokyo, Japan

ABSTRACT

A hydrogen supply chain is constructed to achieve carbon neutrality by 2050. In this situation, a large-scale tank with a capacity of 50,000 m³ is designed as a medium- to long-term storage facility for liquefied hydrogen. Fatigue cracks must be considered since the tanks are subjected to repetitive loading during liquid refilling and earthquakes. Austenitic stainless steel, especially SUS316L, is considered as the preferred material for storage tanks, but its fatigue crack propagation characteristics are unclear. In addition, since the temperature of liquefied hydrogen is extremely low (-253°C), Transformation Induced Plasticity (TRIP) is important.

The relationship between crack growth rate and crack opening/closing behavior is effective in clarifying crack propagation characteristics because it can be easily connected to the theory. Existing theories of crack propagation do not take into account the effect of TRIP. Therefore, it is effective not only to clarify the crack propagation characteristics but also to improve the theory of crack propagation by investigating the effect of TRIP on the crack opening and closing behavior. In this study, low-cycle fatigue tests were conducted at different temperatures, degrees of processing, and materials to investigate the relationship between crack tip opening displacement and crack growth rate. In this study, an alternative material that can be expected to TRIP at room temperature was used. Validation was performed by observing TRIP at the crack tip during loading. EBSD observation of the amount of martensitic transformation was also used to investigate the relationship between the crack tip opening displacement and TRIP. The Schmidt factor for each hypothetically segmented randomly oriented grain is taken into account and its effect on the crack tip opening behavior is quantified through statistical processing. The results can be used to update the theory of crack propagation to include the influence of TRIP.

KEY WORDS

Hydrogen; Stainless steel; Martensitic transformation; Low cycle fatigue; Crack tip opening displacement.

INTRODUCTION

Background

Climate change is caused by greenhouse gases, of which global warming is one of the best examples. In particular, the reduction of carbon dioxide is a common global issue. Accordingly, the term "carbon neutral" has been attracting widespread attention around the world. The goal is to reduce the net amount of carbon dioxide emitted by human activities to zero, and to achieve this goal, it is essential to

expand the use of hydrogen will develop a hydro stably, it is esse than the exist hydrogen is 2 structures have liquefied hydro SUS316L, a m as a material fo its relatively hydrogen emb known that the transformation body-centered brittleness. The cycle fatigue (L

History of M aim of this st

The idea that n has been propo stainless steel, stress and ten dependence w stainless steel, t observed, and induced marten In addition, w fatigue life reg mechanism by properties is th the actual dri compressive re volumetric exp overall stress σ (Schmitt, Kuhn factor, a param not accurately c On the other ha deteriorates fat properties. A ty is under consta because the str as the transform transformation increased strain

KEY WORDS

Liquefied hydrogen storage tank; Austenitic weld metal; Cryogenic toughness; Charpy impact test; Deformation-induced martensitic transformation; Finite element method.

INTRODUCTION

As the world moves toward a decarbonized society, the Japanese government has declared its goal of becoming carbon neutral by 2050; moreover, as part of this, it aims to establish a hydrogen supply chain with a capacity of 300,000 tons per year by 2030. In order to achieve this supply target, a large flat-bottom cylindrical liquefied hydrogen storage tank with a capacity of 50,000 m³ must be constructed to significantly reduce the price of hydrogen. Austenitic stainless steel, which has already been used worldwide as a material for small spherical hydrogen storage tanks because of its resistance to hydrogen embrittlement and low-temperature brittleness, is a promising candidate for the material of the large-scale liquefied hydrogen storage tanks. Considering the long-term operation of storage tanks over several decades, it is important to select materials and optimize welding conditions for welds, which are presumed to have inferior fracture resistance to that of base metals when subjected to large earthquakes and other large strains. However, there have been few studies on the cryogenic toughness of austenitic weld metals; furthermore, in particular, the deformation-induced martensitic transformation behavior during crack propagation, which is assumed to significantly affect the toughness, has not been clarified.

Effects of Deformation-Induced Martensitic Transformation on Cryogenic Toughness of Austenitic Weld Metal

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*Kobe Steel Ltd., Technical Development Group, 1-5-5 Takatsukadai Nishi
*Kobe Steel Ltd., Welding Business, 100-1 Miyamae Fujisawa Kan

ABSTRACT

The effect of deformation-induced martensitic transformation on the cryogenic toughness of welds of austenitic stainless steel, which is a promising candidate material for large liquefied hydrogen storage tank materials, was investigated. From the results of macrostructural observation and FEM analysis in the vicinity of the crack, it was suggested that the amount of deformation-induced martensitic transformation decreased as the temperature increased due to the Charpy impact test compared to static fracture testing. Finally, the possibility of replacing the difficult fracture toughness test with the simple Charpy impact test was discussed.

KEY WORDS: Liquefied hydrogen storage tank; Austenitic weld metal; Cryogenic toughness; Charpy impact test; Deformation-induced martensitic transformation; Finite element method.

INTRODUCTION

As the world moves toward a decarbonized society, the Japanese government has declared its goal of becoming carbon neutral by 2050; moreover, as part of this, it aims to establish a hydrogen supply chain with a capacity of 300,000 tons per year by 2030. In order to achieve this supply target, a large flat-bottom cylindrical liquefied hydrogen storage tank with a capacity of 50,000 m³ must be constructed to significantly reduce the price of hydrogen. Austenitic stainless steel, which has already been used worldwide as a material for small spherical hydrogen storage tanks because of its resistance to hydrogen embrittlement and low-temperature brittleness, is a promising candidate for the material of the large-scale liquefied hydrogen storage tanks. Considering the long-term operation of storage tanks over several decades, it is important to select materials and optimize welding conditions for welds, which are presumed to have inferior fracture resistance to that of base metals when subjected to large earthquakes and other large strains. However, there have been few studies on the cryogenic toughness of austenitic weld metals; furthermore, in particular, the deformation-induced martensitic transformation behavior during crack propagation, which is assumed to significantly affect the toughness, has not been clarified.

In addition to this, fracture toughness (liquefied hydrogen fracture toughness) test at 77 K. How fracture test, cause does not occur in measured the tem impact test at 77 K rise was up to 100 effect on martensit few studies have values and static σ cryogenic temper In this study, Char temperature and 7 GTAW (Gas Tung of deformation- toughness was disc of the cracks. Mo Charpy impact test analysis. Finally, results by the dyn

KEY WORDS: Hydrogen embrittlement, SMAW, SAW, weld metal

INTRODUCTION

In a huge cryogenic storage tank manufacturing, the selection of welding process is an important activity for the project. Both Submerged Arc Welding (SAW) and Shielded Metal Arc Welding (SMAW) are viable processes for stainless steel welding, each with its own strengths and considerations. SAW offers high deposition rates and deep penetration, making it suitable for thick stainless steel sections, but welding position and plate thickness are examples of limiting factors. On the other hand, SMAW, also known as stick welding, is versatile, portable, and can be used in various positions, making it suitable for both thin and thick stainless steel, although it typically has lower deposition rates compared to SAW. Furthermore, while SAW requires a controlled environment due to its submerged nature, SMAW is preferable for outdoor or challenging environments, which induce situations with difficult control of surface contamination and wind conditions. For a cryogenic hydrogen storage tank, SUS316L is one promising candidate that has been studied by many researchers, (Hernis et al., 1999; Michler et al., 2009, 2015; Michler & Neumann, 2008; San

Hydrogen Embrittlement of SAW and SMAW welded joints from the SUS316L at Low Temperature

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Shohei Uramaka*
Yuan Xuecheng*
Mitsuo Kimura*
Tomoya Kawabata*

*The University of Tokyo, Department of Systems Innovation
*The University of Tokyo, Department of Fundamental Engineering
Tokyo, Bunkyo-ku, Japan

ABSTRACT

Hydrogen embrittlement in the SAW and SMAW weld metal is investigated in this work by employing slow strain rate tensile (SSRT) tests and using a scanning electron microscope (SEM) to verify the fracture surface the failure mode. Also, a comparison between the welded joints produced by both welding processes with the SUS316L base plate is made after the tests at -75 °C under three different test pressure and at -40 °C. The loss of ductility and reduction of strengths were observed for both welded metal but in different proportions and it is related to each microstructure produced after welding.

KEY WORDS: Hydrogen embrittlement, SMAW, SAW, weld metal

INTRODUCTION

In a huge cryogenic storage tank manufacturing, the selection of welding process is an important activity for the project. Both Submerged Arc Welding (SAW) and Shielded Metal Arc Welding (SMAW) are viable processes for stainless steel welding, each with its own strengths and considerations. SAW offers high deposition rates and deep penetration, making it suitable for thick stainless steel sections, but welding position and plate thickness are examples of limiting factors. On the other hand, SMAW, also known as stick welding, is versatile, portable, and can be used in various positions, making it suitable for both thin and thick stainless steel, although it typically has lower deposition rates compared to SAW. Furthermore, while SAW requires a controlled environment due to its submerged nature, SMAW is preferable for outdoor or challenging environments, which induce situations with difficult control of surface contamination and wind conditions. For a cryogenic hydrogen storage tank, SUS316L is one promising candidate that has been studied by many researchers, (Hernis et al., 1999; Michler et al., 2009, 2015; Michler & Neumann, 2008; San

Marchi et al., 2008). Although this ste hydrogen embrittlement resistance, the de temperatures, for example between -50 to Freire et al., 2023; Fukuyama et al., 2003. P that this embrittlement phenomenon may h induced martensite, the deformation by e cycling final energy (SFE).

The severity of hydrogen embrittlement metal was verified for a previous project for economy. (Horiya et al., 1996). Also, other weld metal under the influence of hydrogen Luppó, 1999; Younes et al., 2013; Yun et a Tao (Tao et al., 2020) studied a stainless s one microstructure, and the failure mechani the hydrogen embrittlement in a base σ . Therefore, investigations of the hydrogen σ joints of this steel are necessary to define a b process and its parameters.

This current work uses slow strain rate hydrogen environment under three different at -75 °C and under 10 bar at -40 °C to embrittlement performance of SAW and SM cryogenic hydrogen storage tank. The fractu were analyzed in order to verify the failu differences between the weld metal spec

ABSTRACT

There have been a few hydrogen storage tanks made of Transformation induced plasticity (TRIP) steel in the world. However, its fracture property remains unknown. Because the materials are under a complicated environment, exposed to hydrogen, and cryogenic temperature. This study focuses on the pre-straining effect of TRIP steel to assess the aged fracture properties. 10 different pre-straining and two environments, 20K and 77K, were prepared. The results show a great reduction of J value as the pre-strained amount increases both in 20K and 77K. That value would be a reference value to assess the life cycle of the hydrogen storage tank.

KEY WORDS: J integral; Cryogenic temperature; Pre-strainings.

1 INTRODUCTION

1.1 Social Background

Hydrogen attracts attention as a next-generation energy carrier. One of the methods used to transport hydrogen is simple low-temperature liquefaction.

One infrastructure to transport hydrogen is a liquefied hydrogen storage tank. The tank is a vessel that stores liquefied hydrogen at a temperature of 20 K. The tank is made of low-temperature-durable material, such as stainless steel, aluminum alloy, titanium alloy, or composite material. Here, the discussion will focus on metastable Austenite (γ) stainless steels, which were considered promising candidates in Japan's national project called International Hydrogen Energy Network (WE-NET). There are two reasons for their practicality. (1) Metals with an Face-centered cubic (FCC) crystal structure are less affected by hydrogen embrittlement and exhibit stable crack propagation compared to those with a Body-centered cubic (BCC) structure. (2) Among FCC materials, metastable γ stainless steels are the most cost-effective.

However, the cheaper the metastable γ stainless steel, the more susceptible it is to transformation into the BCC structure's α' , thus requiring a balance between cost-effectiveness and fracture toughness. As a result of WE-NET, it is concluded that considering economic viability, existing stainless steels such as SUS304L and SUS316L become candidates for low-temperature materials used in initial liquefied hydrogen storage tanks. However, this evaluation is solely based on the results of the Slow strain rate tensile test (SSRT) and the Charpy impact test results, and there has

hardly been any verification of the fracture toughness (Critical J (J_{IC})) and fatigue characteristics of materials affected by hydrogen brittleness under extremely low temperatures of about 20K. In other words, it has not taken into consideration the effects on the material properties of the base metal and weldments under extremely low temperatures caused by repeated plastic strain due to earthquakes and other causes. Including fracture toughness in the impact assessment is very important when constructing large-scale storage tank facilities. This is because the impact range can be extremely wide if destruction involving a large-scale leak and fire occurs when hydrogen storage tanks are installed on land relatively close to consumption areas. Furthermore, if approvals for the start of manufacturing of liquefied hydrogen storage tanks are to be granted annually, it is essential not only to present impact assessments but also to set standards for materials and welding that consider the most severe conditions for the materials used, to prevent major accidents such as massive leaks of liquid hydrogen.

1.2 Importance of the Theme

Considering the background above, it is extremely important to consider the residual fracture toughness after the application of pre-strain. For instance, imagine constructing and maintaining a large-scale hydrogen storage tank, and then an earthquake occurs. It is a fundamental premise to ensure the toughness to withstand this seismic activity, but without knowing the fracture toughness after the application of pre-strain, it cannot be determined whether it is safe to continue using it.

1.3 Survey about J and TRIP

Directly measuring pre-strained fracture toughness parameters, as represented by the J integral (J), is one way for fracture assessment. Of course, it is possible to consider the above scenario as low cycle fatigue and characterize the fracture property as fatigue property. However, it is also important to assess the degradation of material property itself, not only the crack-extending effect. Additionally, the frequency of encountering earthquakes in this scenario is at most a few times throughout the operation.

However, especially in Transformation induced plasticity (TRIP) steel, there are the following issues in accurately quantifying the "fracture toughness with no strain", which is a preliminary milestone to assess the pre-strained fracture toughness.

(1) Because it is difficult to simply express Martensitic transformation ($\gamma \rightarrow \alpha'$) in Finite element analysis (FEA), J integral ($J_{max, integral}$) cannot be calculated. (2) Because $J_{max, integral}$ cannot be calculated,

Experimental Evaluation of J integral Suffering from Pre-strainings at Cryogenic Temperature, SUS316L

Ritsuki Morohoshi, Tomoya Kawabata
The University of Tokyo, 7-3-1 Hongo Bunkyo-ku Tokyo, Japan

4. 今後の見通しについて

今次事業

年度	22	23	24	25	26	27	28	29	30	31
実証プラント 設計/申請/ 建設/運用 (参考)				設計	建設		実証運転			
商用プラント 設計/申請/ 建設/運用				申請	設計 立地交渉	建設		運用開始		商用運転
材料・溶接 土木評価研究	[Red Box]		[Red Box]		[Red Box]		[Red Box]		[Red Box]	
能代試験場 設置										
指針原案作成 (HPIS)	ドラフト完成			完成						
指針審議 委員会										

本事業において大型液化水素貯槽候補材の詳細特性評価および実大試験の準備を実施できた。さらに**必要特性の見極めてを経て技術指針策定を目指す**。策定する指針は2030年に政府ロードマップに従って実現すべき貯槽製作の技術的基礎となるだろう。

今後も液化水素貯槽の技術基盤確立のために尽力し、地球環境問題に貢献するとともに、我が国の今後の技術資産形成の一翼を担いたい。