

# SHINAGAWA TECHNICAL REPORT

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機械的特性の改善

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## 品川技報

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## Improvement of Mechanical Characteristics of Basic Bricks for Cement Rotary Kiln

|                         |                       |
|-------------------------|-----------------------|
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### 要 旨

セメントロータリーキルンは回転炉であり、内張りれんがはシェルの円周方向の変形や軸方向の動きなどに伴う複雑な機械的応力を繰り返し受けるため、剥離損傷を生じやすい。そのため、れんがの機械的応力に対する抵抗性を改善することはれんがの耐用性向上に重要である。本報告では、当社セメントロータリーキルン用塩基性れんがについて、従来の評価項目に加え、特に熱機械的特性に注目した結果と、その使用実績について述べる。

### Abstract

The refractory lining for cement rotary kiln (furnace) is often damaged by mechanical spalling because it is mechanically stressed by both circumferential deformation and axial movement of the kiln shell repeatedly. Therefore, improving mechanical stress resistance is important for prolonging the service-life of the refractory lining. We evaluated not only the conventionally physical characteristics of cement rotary kiln refractories but also the thermos-mechanical characteristics. We report on some new evaluation methods and explain some refractory performance results for the cement rotary kiln.

### 1. はじめに

セメントロータリーキルン（以下、セメントキルン）は、セメント製造装置であるとともに、産業廃棄物をセメント原燃料としてリサイクルする重要な役割を担っている。しかし、近年セメントキルンに装入される産業廃棄物の使用比率が増加し、廃棄物の種類も多様化しているため<sup>1)</sup>、サルファーやアルカリ、塩素などの影響を受け、内張

### 1. Introduction

The role of the cement rotary kiln (hereinafter referred to as cement kiln in this paper) are cement manufacturing equipment and recycling equipment which turn industrial wastes into cement raw materials and fuel resources. Recently, more industrial waste is added to cement raw material and more types of

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りれんがの保護層となるコーティングが不安定化している。コーティングが不安定化すると、れんがの摩耗損傷、組織脆化、溶損が起りやすくなる。またセメントキルンはシェルの円周方向の変形や軸方向の動きなどに伴う機械的応力を繰り返し受ける<sup>2)~5)</sup>。そのため、れんがは厚い剥離や圧壊によって損傷することがある。

セメントキルン用れんがに要求される特性として、耐摩耗性、耐熱脆化性、耐溶損性が重視されるが、それらに加えて変形能や応力緩和性などの機械的特性を向上させることが必要と考える。れんがの機械的特性を評価する方法として、曲げや圧縮など一軸方向の応力による評価方法が主であるが<sup>6)~8)</sup>、複雑な応力を受けるセメントキルン用れんがは、せん断やねじりなどを考慮した試験がより望ましい<sup>9)</sup>。本報告では当社セメントキルン用れんがについて、従来の評価項目に加え、特に熱機械的特性に注目した結果とその使用実績について述べる。

## 2. 損傷要因と要求特性

代表的なセメントキルンのライニングをFig.1に示す。セメントキルンは出口側から冷却帯、焼成帯、遷移帯、仮焼帯に分けられる。温度や雰囲気は各ゾーンで異なっており、それぞれ特徴的な損傷を示す<sup>4), 9)</sup>。冷却帯から遷移帯は損傷が大きく、主にマグネシアースピネル質れんがが使用される。仮焼帯は比較的低温で損傷が軽微であり、高アルミナれんがやシャモットれんがが使用される。

冷却帯は比較的高温であるが、焼成帯に比べてコーティングが不安定なため熱変動が大きく、セメントクリンカーによる摩耗や熱的スポーリングが主な損傷要因である。また、冷却帯のセメント

industrial waste have been used. Sulfur, alkali, chlorine components in industrial waste make the cement coating protecting the refractory unstable. They accelerate abrasion, structural deterioration and corrosion of refractories. The refractory lining is mechanically stressed by both circumferential deformation and axial movement of kiln shell repeatedly. Therefore, it is often damaged by mechanical spalling.

Abrasion resistance, thermal embrittlement resistance and corrosion resistance are important characteristics for cement kiln refractories. We consider deformability and stress relaxation characteristics to also be important. To evaluate the mechanical characteristics of the refractories, uniaxial stress examinations of bending and compression are widely used. But examinations of shear and torsion are more desirable because the stress elements in cement kiln refractories are complex. This paper not only the conventional physical characteristic evaluations but also thermos-mechanical characteristics of basic refractories for cement rotary kilns and improved materials performance results.

## 2. Damage Factors and Required Refractory Characteristics

Figure 1 shows a representative refractory lining for a cement kiln. The cement kiln is divided into a cooling zone, burning zone, transition zone and calcining zone in that order from the outlet side. Each zone has a different temperature and atmosphere and wear configuration. Magnesiaspinel bricks are widely used in the area from

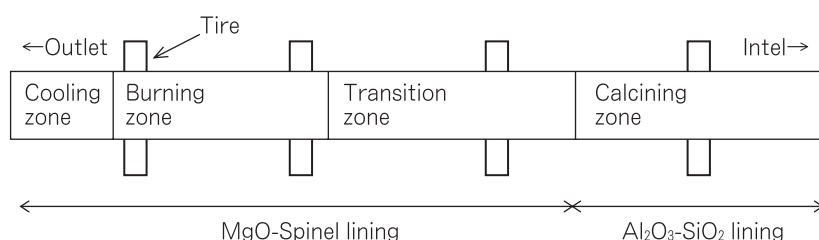


Fig.1 Typical refractory lining of cement rotary kiln.

キルン出口端のシェルは長期にわたって熱を受け、次第にラッパ状に変形する。そのため、内張りれんがは拘束が緩み、スリップや変形などの影響で圧壊が生じる場合がある。よって、冷却帯は耐摩耗性、容積安定性・耐熱脆化性および変形能が要求される。

焼成帯は最も温度が高くセメントクリンカー中の液相が多いため、れんが表層にコーティングが形成されている。しかし、コーティングが剥離した時は最も高い熱負荷にさらされるため、溶損が増大する。また、支点部では機械的スポーリングによる損傷も発生する。よって、焼成帯は耐溶損性、変形能・応力緩和性が要求される。

遷移帯は焼成帯よりも低温でクリンカー中の液相量が少なく、炉内が低酸素雰囲気であるためコーティングが不安定である。そのため、コーティング脱着によるれんが表面温度の変動が大きく、熱スポーリングが主な損傷要因となる。また遷移帯はセメントキルンの中央に位置するため、シェルのたわみにより機械的応力が発生しやすく、特に支点部で機械的スポーリングが起こりやすい。よって、遷移帯は容積安定性・耐熱脆化性、変形能・応力緩和性が要求される。

### 3. 評価方法

#### 3.1 評価試料

冷却帯用れんがの品質をTable 1に示す。「SP-8D」は主に高純度マグネシアおよびスピネルを使用した標準品である。「SP-8DC」は鉄成分を添加しコーティング付着性を向上させるとともに、熱間強度も向上させた品質である。「SP-8DF」は強度を維持しつつ組織内にギャップを導入し変形能・応力緩和性を付与した品質である。

Table 1 Typical properties of MgO-Spinel bricks for cooling zone

| Brand                             |                                | SP-8D | SP-8DC | SP-8DF |
|-----------------------------------|--------------------------------|-------|--------|--------|
| Apparent porosity/ %              |                                | 15.5  | 15.3   | 16.1   |
| Bulk density / g•cm <sup>-3</sup> |                                | 3.05  | 3.05   | 2.94   |
| Cold crushing strength/MPa        |                                | 54    | 57     | 52     |
| Chemical composition<br>/ mass %  | MgO                            | 81    | 80     | 83     |
|                                   | Al <sub>2</sub> O <sub>3</sub> | 17.6  | 17.6   | 15.8   |
|                                   | Fe <sub>2</sub> O <sub>3</sub> | —     | 1.5    | 0.2    |

the cooling zone to the transition zone because they are damaged severely. High alumina and fireclay refractories are widely used in the calcining zone because they are damaged only slightly at relatively low temperatures.

The cooling zone is relatively high in temperature. The refractories are exposed to large temperature change because the coating on the cooling zone refractories is not stable compared to that on the burning zone refractories. Abrasion by cement clinker and thermal spalling are the main damages to the cooling zone refractories. The steel shell on the cement kiln is heated at high temperature for a long term. The shell around the outlet gradually deforms and flares out at the edge. As the shell restriction loosens the refractory lining sometimes slips out and/or crush and falls down by mechanical stress. Therefore, the refractories in the cooling zone require abrasion resistance, volume stability, thermal embrittlement resistance and deformability.

The burning zone has the highest temperature in the kiln. The cement clinkers have a lot of liquid phase and coat refractories. Once the coating disappears from the surface, the refractory lining is exposed to considerably high temperature conditions and is corroded severely. Mechanical spalling also occurs at the tire areas. Burning zone refractories are required for corrosion resistance, deformability and stress relaxation.

The transition zone is lower in temperature than the burning zone and has a low-oxygen atmosphere. The cement clinkers in the transition zone have less liquid phase and the coating is less stable than burning zone. Repeated attachment and detachment of the cement coating causes temperature change of refractories. Thermal spalling is the main damage. Moreover, the transition zone is located at the center of the cement kiln. The shell is deformed rather largely at the tire areas, which causes

**Table 2 Typical properties of MgO-Spinel bricks for burning zone**

| Brand                             |                                | ELK-12CX-1 | ELK-11CW | ELK-12CXR |
|-----------------------------------|--------------------------------|------------|----------|-----------|
| Apparent porosity / %             |                                | 14.5       | 14.0     | 15.7      |
| Bulk density / g·cm <sup>-3</sup> |                                | 3.04       | 3.06     | 3.02      |
| Cold crushing strength / MPa      |                                | 56         | 60       | 54        |
| Chemical composition / mass %     | MgO                            | 86         | 85       | 83        |
|                                   | Al <sub>2</sub> O <sub>3</sub> | 10.8       | 12.2     | 12.2      |
|                                   | Fe <sub>2</sub> O <sub>3</sub> | 1.2        | 1.0      | 1.4       |

**Table 3 Typical properties of MgO-Spinel bricks for transition zone**

| Brand                             |                                | SP-8L | SP-8LS | SP-8LDF |
|-----------------------------------|--------------------------------|-------|--------|---------|
| Apparent porosity / %             |                                | 15.5  | 14.8   | 15.1    |
| Bulk density / g·cm <sup>-3</sup> |                                | 2.95  | 3.00   | 3.00    |
| Cold crushing strength / MPa      |                                | 48    | 54     | 50      |
| Chemical composition / mass %     | MgO                            | 81    | 81     | 81      |
|                                   | Al <sub>2</sub> O <sub>3</sub> | 17.7  | 17.4   | 17.6    |
|                                   | CaO                            | 0.6   | 0.7    | 0.7     |

**Table 4 Chemical composition of reactant**

|        | CaO | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | K <sub>2</sub> O+SO <sub>3</sub> +Cl |
|--------|-----|------------------|--------------------------------|--------------------------------|--------------------------------------|
| mass % | 62  | 20               | 5.5                            | 2.5                            | 10                                   |

焼成帯用れんがの品質をTable 2に示す。「ELK-12CX-1」は、耐食性とコーティング付着性とのバランスが良好な標準品質で、焼成帯全域に使用可能である。「ELK-11CW」は高耐食性かつコーティング付着性を有し、熱負荷が高い真焼点に使用される。「ELK-12CXR」は耐食性を維持しつつ組織内にギャップを導入し変形能・応力緩和性を付与した品質である。

遷移帯用れんがの品質をTable 3に示す。「SP-8L」はサルファー等の侵入抑制のため緻密化と低通気率化した品質である。「SP-8LS」は特殊添加物により熱間強度を向上させた品質である。「SP-8LDF」は緻密性を維持しつつ組織内にギャップを導入し変形能・応力緩和性を付与した品質である。いずれの品質もサルファー成分に対する化学的反応を抑制するため、低CaO化を図っている<sup>10)</sup>。

mechanical stress. The mechanical spalling often happens at the tire areas. Transition zone refractories are required to have volume stability, thermal embrittlement resistance, deformability and stress relaxation.

### 3. Evaluation Method

#### 3. 1 Evaluation sample

Table 1 shows the typical properties of our products for the cooling zone. SP-8D is a standard product using mainly high purity magnesia and spinel. SP-8DC contains some Fe components and is a product with improved coating adhesion and high hot modulus of rupture. SP-8DF has gaps in the texture and is a product with deformability, stress relaxation and enough high strength.

Table 2 shows the typical properties of our products for the burning zone. ELK-12CX-1 is a standard product with good corrosion-resistance and coating adhesion. It is suitable for the whole burning zone. ELK-11CW has good corrosion resistance and coating adhesion. It is suitable for most high temperature areas. ELK-12CXR has gaps in the texture and is a product with deformability, stress relaxation and good corrosion resistance.

Table 3 shows the typical properties of our refractories for transition zone. SP-8L is a product designed to have low porosity and permeability in order to suppress the infiltration of foreign compositions such as sulfur into brick. SP-8LS contains special additives and has a high hot modulus of rupture. SP-8LDF has gaps in the texture and has good deformability, stress relaxation and dense texture.

All our products for transition zone are designed to have low CaO amounts in order to suppress chemical reaction between sulfur and CaO composition.

#### 3. 2 Abrasion resistance

We conducted an abrasion resistance test for the cooling zone refractories which are required

### 3. 2 耐摩耗性

耐摩耗性が要求される冷却帯用れんがについて、耐摩耗試験を行った。試験温度は1250℃とし、試験はJIS R 2252-2「耐火物製品の耐摩耗性の評価試験方法－第2部：熱間法」により実施した。

### 3. 3 容積安定性・耐熱脆化性

容積安定性・耐熱脆化性が要求される冷却帯用および遷移帯用れんがについて、加熱冷却の繰り返し試験前後の線変化率と弾性率（グラインドソニック法）の変化を評価した。試験条件について、冷却帯は高温での繰り返しの加熱冷却サイクルを想定し、電気炉で1400℃×15分間加熱し、900℃×15分間自然冷却するサイクルを5回繰り返す試験を行なった。遷移帯は温度変動の大きい加熱冷却サイクルを想定し、電気炉で1300℃×10分加熱し、室温で10分間自然冷却するサイクルを30回繰り返す試験を行なった。

### 3. 4 耐食性

耐食性が要求される焼成帯用れんがについて、回転ドラム侵食試験を行った<sup>11)</sup>。試験温度は1700℃×5hで、侵食材にはTable 4に示す合成スラグを使用した。試験後試料の切断面から溶損面積を測定し、標準品との比較で耐食性を評価した。

### 3. 5 熱機械的特性

高温でせん断変形を受けた場合の熱機械的特性を評価するため、全ての試料についてねじり試験を行った<sup>12)</sup>。ねじり試験装置をFig.2に示す。試料は20×20×230mmの直方体で、両端20mmは治具に固定されている。一方の治具にはトルク検出器が設置されており、反対側の試料端がねじられると試料を介してトルクが検出される仕組みとなっている。また、試験機全体のねじれ角を角度検出器により測定している。

試料中心部115mmの領域を1250℃に均一加熱し10分保持後、トルク検出器が200N・cmになるまで一定のトルク速度（1秒間に100N・cm）でねじっていき、トルクとねじれ角の曲線をチャート用紙に記録、測定した。その後、チャート用紙の記録から試料のトルクMとねじれ角 $\gamma$ の関係を算出し、式(1)を用いてねじり剛性率を求めた。また、焼成帯用および遷移帯用のれんが試料については200N・cmにねじった後固定し、1時間経過後のトルク－時間曲線（トルク緩和曲線）を記録し

to have good abrasion resistance. The examination temperature was 1250℃ and examination was done under JIS R 2252-(2), test method for abrasion resistance of refractory products.

### 3. 3 Volume stability and thermal embrittlement resistance

We evaluated the volume stability and thermal embrittlement resistance for cooling and transition zones refractories. The evaluation uses the linear change and elasticity change from the original and after heat-treatment in an electric furnace. The modulus elasticity was measured by grind sonic method. The cooling zone refractories were heat-treated in 5 cycles of heating at 1400℃ for 15 minutes and cooling down to 900℃ for 15 minutes. That was the supposed temperature change in the high temperature range. The transition zone refractories were heat-treated for 30 cycles of heating at 1300℃ for 10 minutes and cooling down to room temperature for 10 minutes. Those were the supposed rapid and furious temperature change conditions.

### 3. 4 Corrosion resistance

We conducted a rotary drum corrosion test for the burning zone refractories which are required to have good corrosion resistance. The examination was done at 1700℃ for 5 hours using the synthetic slag shown in Table 4 as the corrosion agent. The corrosion resistance was evaluated by comparison with a standard brick (ELK-12CX-1) to measure the corrosion area on cross sections of the refractory samples after the test.

### 3. 5 Thermal mechanical characteristic

We carried out a torsion test for all the refractory samples in order to evaluate the thermal mechanical characteristics against shear stress at high temperature. Figure 2 shows the torsion test apparatus. The dimensions of the specimens are 20×20×230mm length. Both ends (=20mm) of a sample are fixed by jigs. The torque detector is attached on one jig. Twisting the other jig,

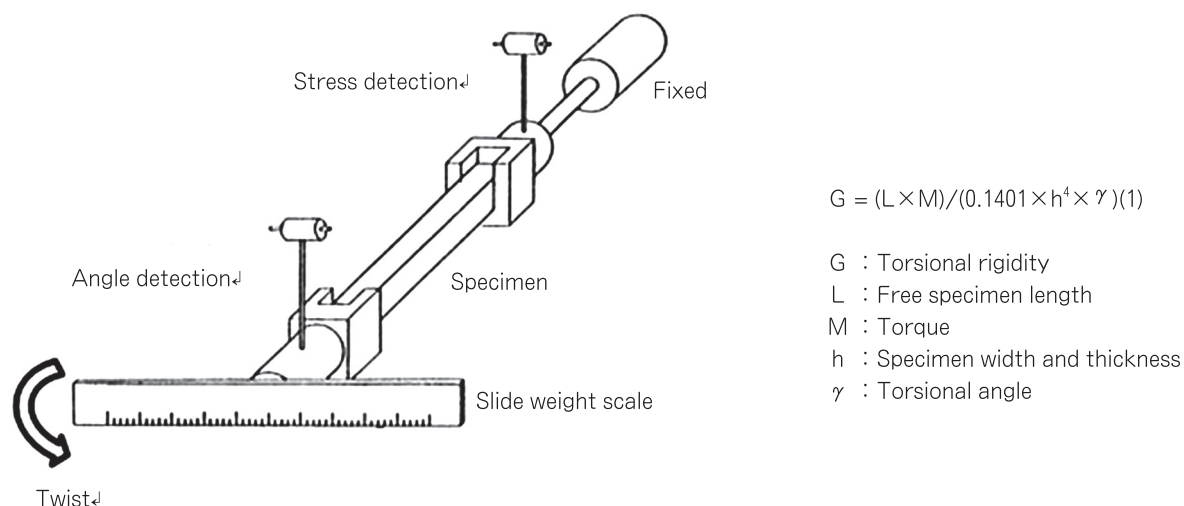


Fig.2 Experimental torsion test apparatus.

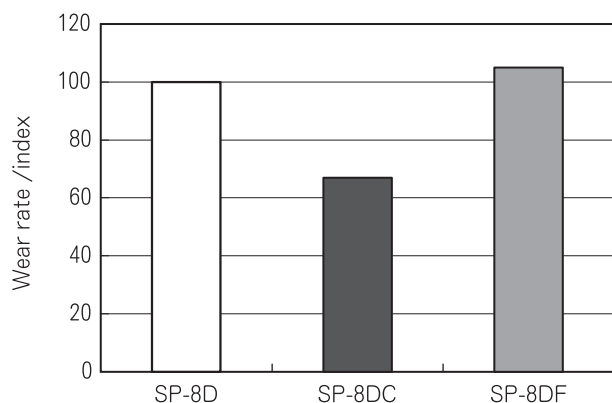


Fig.3 Wear rate of cooling zone refractories by hot abrasion test.

た。ねじり剛性率が低いものは変形能に優れ、トルク緩和量の大きいものは応力緩和性に優れると判断した。

#### 4. 結果及び考察

##### 4.1 耐摩耗性

冷却帯用れんがの耐摩耗試験の結果をFig.3に示す。標準品「SP-8D」に比べて「SP-8DC」は摩耗量が約30%小さく、「SP-8DF」はほぼ同等であった。

##### 4.2 容積安定性・耐熱脆化性

冷却帯用れんがの繰り返し加熱後の線変化率をFig.4に示す。線変化率は経験的に1.0%以下であれば問題ないことがわかっている。繰り返し加熱

the torque reaches to the other jig through the sample. The angle detector measures torsion angle of the whole apparatus.

The center part of the 115mm sample was heated to 1250℃ and kept at that temperature for 10 minutes. The sample was twisted to 200N·cm at 100N·cm per second. The torque and torsion angle curves were recorded on a chart. The torsional rigidity was calculated using equation (1) in Fig.2 based on torque  $M$  and torsional angle  $\gamma$  on the chart.

We also measured the stress relaxation for the burning zone and transition zone samples. They were twisted to 200N·cm torque and kept in the twisted condition for an hour. The torque and time curves were recorded on a chart. We considered the torque change to be the stress relaxation. We consider lower torsional rigidity to mean better deformability and larger torque relaxation, which render better stress relaxation.

#### 4. Results and Discussion

##### 4.1 Abrasion resistance

Figure 3 shows the result of the abrasion examination for cooling zone refractories. SP-8DC had approximately 30% less abrasion than

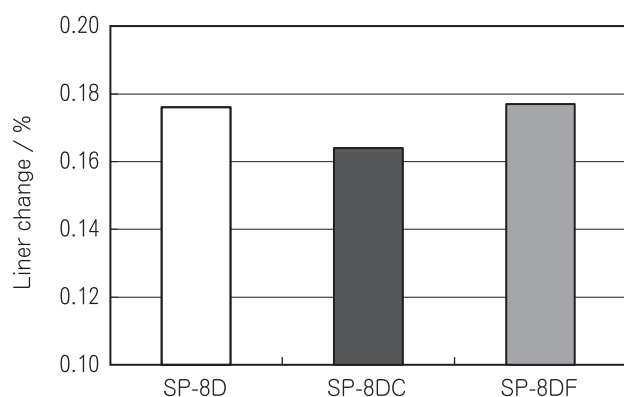


Fig.4 Linear change of cooling zone refractories after heat-treatment.

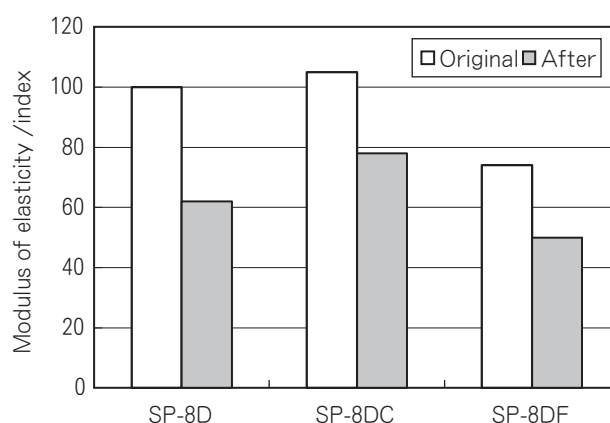


Fig.5 Modulus of elasticity change for cooling zone refractories after heat-treatment.

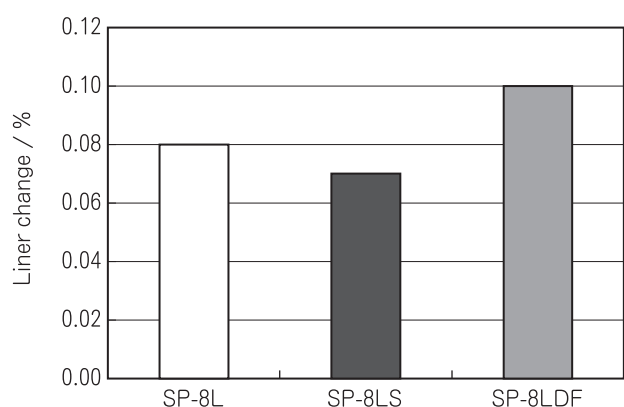


Fig.6 Linear change for transition zone refractories after heat-treatment.

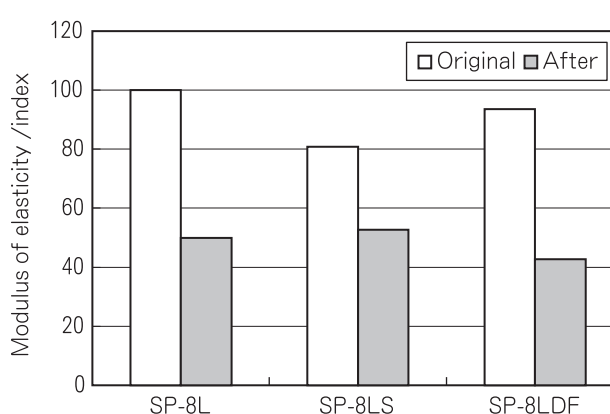


Fig.7 Modulus of elasticity change for transition zone refractories after heat-treatment.

後の線変化率は各品質とも0.2%未満であり、容積安定性に問題はない。また、繰り返し加熱後の弾性率変化をFig.5に示す。繰り返し加熱後の弾性率は、「SP-8D」が約40%低下しているのに対して、「SP-8DC」、「SP-8DF」は約25%低下に抑えられている。

遷移帯用れんがの繰り返し加熱後の線変化率をFig.6に示す。繰り返し加熱後の線変化率は各品質とも1.0%以下であり、容積安定性に問題はない。また繰り返し加熱後の弾性率変化をFig.7に示す。繰り返し加熱後の弾性率は、標準品「SP-8L」が約50%低下しているのに対して、「SP-8LS」は約30%低下に抑えられている。一方「SP-8LDF」の弾性率は約50%低下しており、標準品「SP-8L」とほぼ同等であった。

the standard SP-8DC. The abrasion of SP-8DF was approximately equal to SP-8DC.

## 4. 2 Volume stability and thermal embrittlement resistance

Figure 4 shows the linear change for the cooling zone refractories after heat-treatment. It is empirically known that linear change should be less than 1.0% in consideration of volume stability. The linear changes of all the products were less than 0.2%, which shows superior volume stability. Figure 5 shows the modulus of elasticity change after heat-treatment. SP-8DC and SP-8DF decreased by approximately 25% after heat-treatment although SP-8D decreased by approximately 40%.

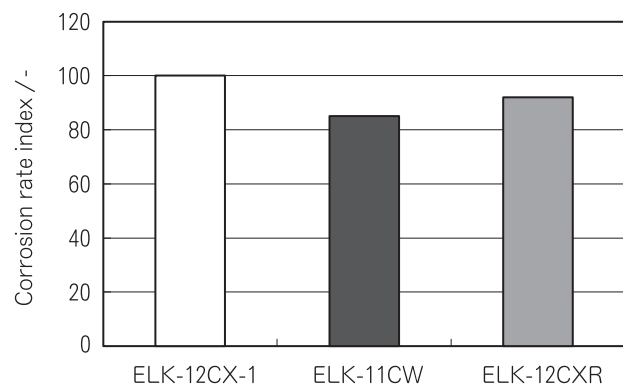


Fig.8 Corrosion rate index of refractories by rotary drum corrosion test.

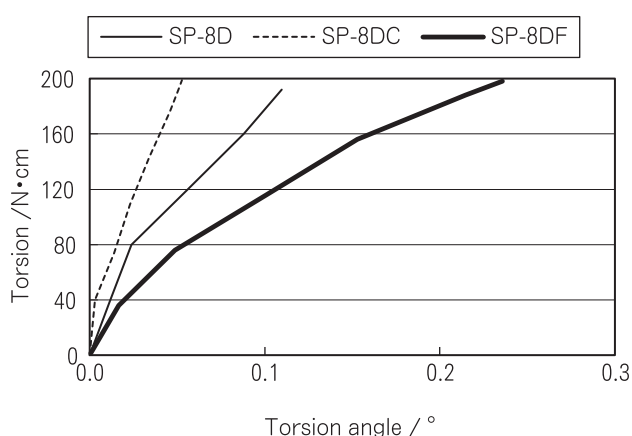


Fig.9 Torque-torsional angle curves of magnesia-spinel bricks for cooling zone by torsional test at 1250°C.

#### 4. 3 耐食性

焼成帯用れんがの耐食性試験結果をFig.8に示す。「ELK-11CW」は最も損傷が少なく、「ELK-12CXR」も標準品「ELK-12CX-1」と同等以上の耐食性を示した。

#### 4. 4 機械的特性

冷却帯用れんがの熱間ねじり試験によるトルク-ねじれ角曲線をFig.9に示す。標準品「SP-8D」に比べて、組織内にギャップを導入した「SP-8DF」はトルクに対するねじれ角が大きい。トルク-ねじれ角の関係から求めたねじり剛性率をFig.10に示す。標準品「SP-8D」に比べて「SP-8DF」はねじり剛性率が約30%小さかった。変形能が要求される変形したシェル部には「SP-8DF」が適すると考えられる。

焼成帯用れんがの熱間ねじり試験によるトル

Figure 6 shows the linear change for the transition zone refractories after heat-treatment. The linear changes of all products were less than 1.0%, which shows good volume stability. Figure 7 shows the modulus of elasticity change after heat-treatment. SP-8LS decreased by approximately 30%. The standard SP-8L decreased by approximately 50%. SP-8LDF decreased approximately 50% and was equal to SP-8L.

#### 4. 3 Corrosion resistance

Figure 8 shows the corrosion test result for burning zone refractories. ELK-11CW showed best wear resistance. The wear resistance of ELK-12CXR was better than the standard ELK-12CX-1 brick.

#### 4. 4 Mechanical characteristic

Figure 9 shows the torque and torsional angle curves for cooling zone refractories by torsional test. The torsional angle against torque of SP-8DF, which has gaps in their texture, was lower than that of the standard SP-8D. The torsion rigidity of SP-8DF was approximately 30% smaller than that of the standard SP-8D refractory (Fig.10). SP-8DF is considered to have more deformability and is a more suitable material for the deformed shell areas.

Figure 11 shows the torque and torsional angle curves for burning zone refractories by torsional test. The torsional angle against the torque of ELK-12CXR, which has gaps in their texture, was lower than that of standard ELK-12CX-1. The torsion rigidity of ELK-12CXR was approximately 30% smaller than that of the standard ELK-12CX-1 (Fig.12). Figure 13 shows the stress relaxation curves for the burning zone refractories. The stress relaxation of ELK-12CXR was larger than that of the standard ELK-12CX-1. ELK-12CXR is considered to have has more deformability and stress relaxation, and is more suitable to the tire areas.

Figure 14 shows the torque and torsional

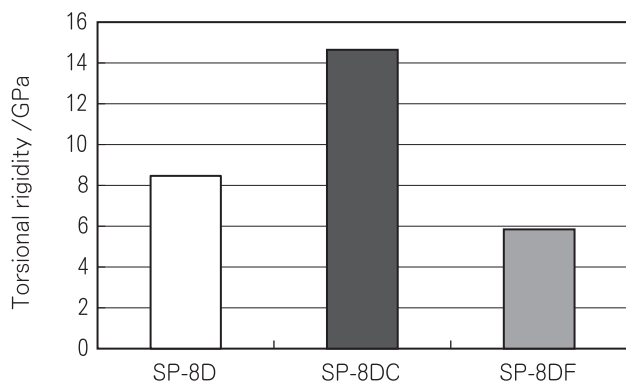


Fig. 10 Torsional rigidity index of magnesia-spinel bricks for cooling zone by torsional test at 1250°C.

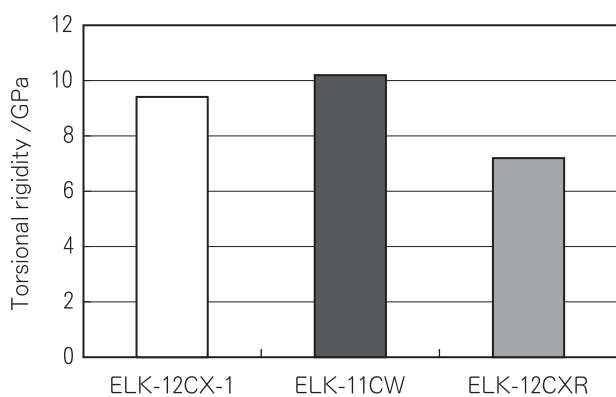


Fig. 12 Torsional rigidity index of magnesia-spinel bricks for cooling zone by torsional test at 1250°C.

クーねじれ角曲線をFig.11に示す。標準品「ELK-12CX-1」に比べて、組織内にギャップを導入した「ELK-12CXR」はトルクに対するねじれ角が大きい。Fig.12に熱間ねじり剛性率を示す。標準品「ELK-12CX-1」に比べて「ELK-12CXR」はねじり剛性率が約30%小さかった。Fig.13にねじり応力緩和曲線を示す。標準品「ELK-12CX-1」に比べて、「ELK-12CXR」の応力緩和性は大きい。変形能・応力緩和性を要求される支点部には「ELK-12CXR」が適すると考えられる。

遷移帯用れんがの熱間ねじり試験によるトルク－ねじれ角曲線をFig.14に示す。標準品「SP-8L」に比べて、「SP-8LDF」はトルクに対するねじれ角が大きく、「SP-8LS」は同等である。Fig.15に熱間ねじり剛性率を示す。標準品「SP-8L」に比べて「SP-8LDF」はねじり剛性率が約45%小さく、

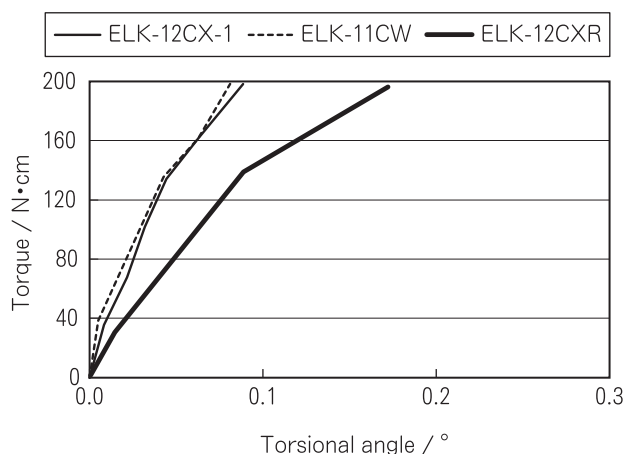


Fig. 11 Torque-torsional angle curves of magnesia-spinel bricks for burning zone by torsional test at 1250°C.

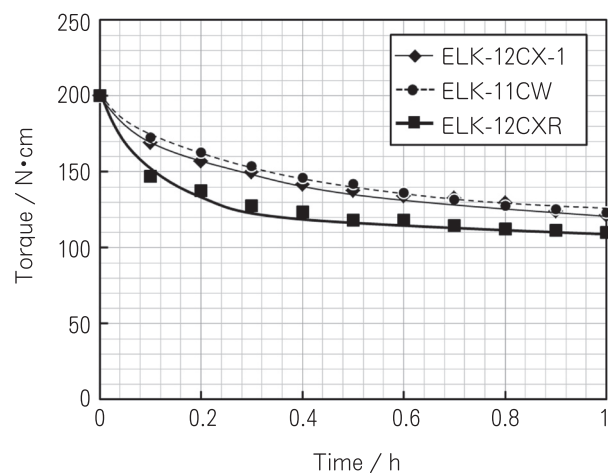


Fig. 13 Torque change of magnesia-spinel bricks for burning zone at 1250 °C by torsional test.

angle curves for the transition zone refractories by torsional test. Compared to the torque of SP-8LDF, the torsional angle was lower than that of standard SP-8L. SP-8LS was equal to SP-8L. Figure 15 shows the torsional rigidity at 1250°C. The torsion rigidity of SP-8LDF was smaller by approximately 45% than that of the standard SP-8L. That of SP-8LS was larger than that of SP-8L by approximately 30%. Figure 16 shows stress relaxation curves for transition zone refractories. The stress relaxation of SP-8LDF was the biggest in all

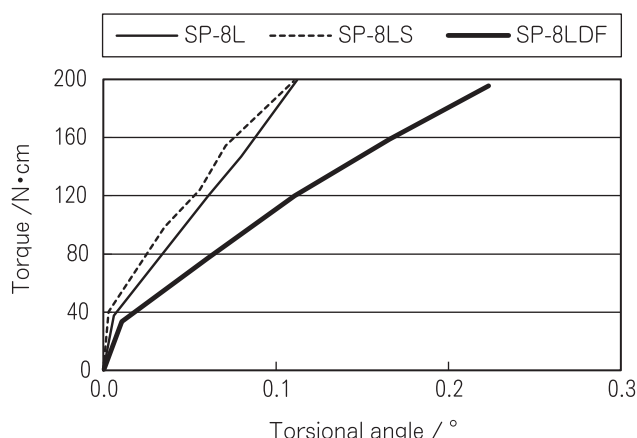


Fig. 14 Torque-torsional angle curves of magnesia-spinel bricks for transition zone by torsional test at 1250°C.

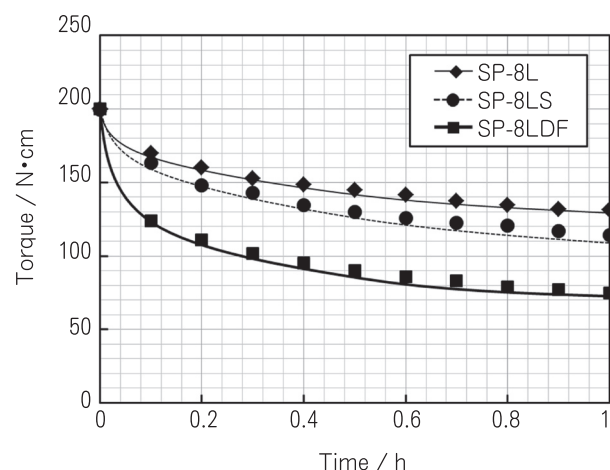


Fig. 16 Torque change of magnesia-spinel bricks for transition zone by torsional test.

「SP-8LS」は約30%大きい。Fig.16にねじり応力緩和曲線を示す。標準品「SP-8L」に比べて、「SP-8LDF」の応力緩和性は最も大きい。変形能、応力緩和性を要求される支点部には「SP-8LDF」が適すると考えられる。

## 5. 実機使用実績

### 5. 1 冷却帯

Fig.17(a)に大径SPセメントキルン冷却帯の出口端に約3ヶ月間使用された標準品「SP-8D」の炉内状況を示す。れんがは稼働面から約110mm位置で大きく剥離し、機械的応力による深層剥離が顕著な損傷状況である。縦目地部の損傷も散見される状況であり、繰り返しの機械的応力によって

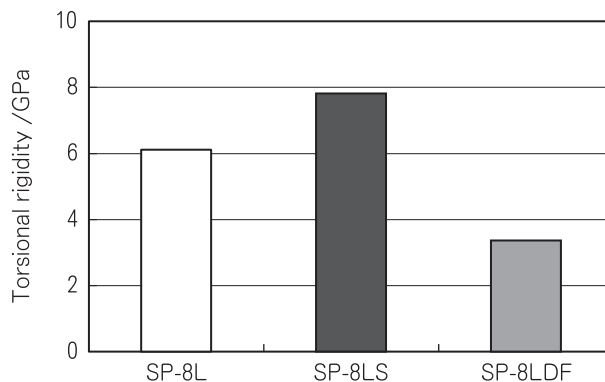


Fig. 15 Torsional rigidity index of magnesia-spinel bricks for transition zone by torsional test at 1250°C.

of them. SP-8LDF is considered to have more deformability and stress relaxation and is more suitable for the tire areas.

## 5. Performance at Actual Cement Kilns

### 5. 1 Cooling zone

Figure 17(a) shows the appearance of the standard SP-8D after 3 months of service at the outlet end area of an SP kiln. SP-D refractories were damaged severely and peeled off 110 mm from the working surface by mechanical spalling. Heavy joint wear was also observed. The bricks are considered to have been damaged by repeated mechanical stress.

Figure 17(b) shows the appearance of SP-8DF, with low torsional rigidity, after 3 months of service at the same area. Some joint wears can be observed, however, there is no peeling off by mechanical spalling issue. The durability of SP-8DF improved from 1 campaign (3 months) to 2 campaigns (6 months).

### 5. 2 Transition zone

Figure 18(a) shows the appearance of SP-8L and SP-8LDF used at the position of  $L/D = 9.9 \sim 10.9$  ( $L$ : distance from the outlet,  $D$ : diameter of the cement kiln) near the tire area in an NSP kiln after 6 months of service. In this area, heavy mechanical stress frequently attacked refractories and joints were worn significantly.

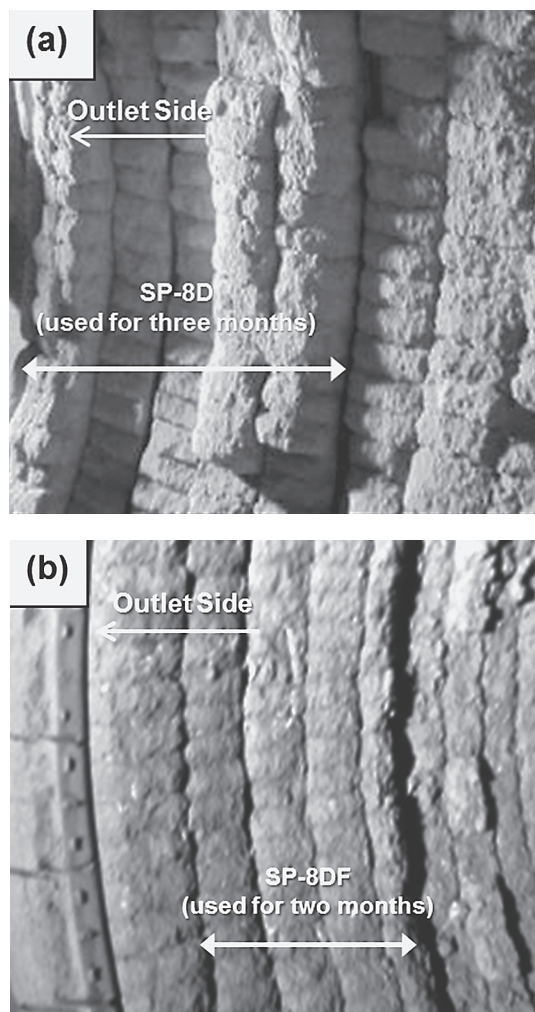


Fig.17 Appearance comparison between (a) SP-8D and (b)SP-8DF used at outlet end of a SP kiln.

損傷していると考えられる。この部位にねじり剛性が低い「SP-8DF」を適用し、約3ヶ月間使用した炉内の状況をFig.17(b)に示す。れんが稼働面はわずかに目地部の損傷が散見されていたが、機械的応力による深層剥離の損傷が解消された。その結果1運転（3ヶ月）から2運転（6ヶ月）への耐用改善を実現した。

## 5. 2 遷移帯

Fig.18(a)に小径NSPセメントキルンの $L/D = 9.9 \sim 10.9$ （ $L$ ：落ち口からの距離、 $D$ ：セメントキルン径）の支点部付近の約6ヶ月間使用後の炉内状況を示す。該部は従来から機械的応力が大きく、目地切れが多発し剥離損傷が激しい部位である。上手側の $L/D = 10.9 \sim 11.5$ で同期間使用され

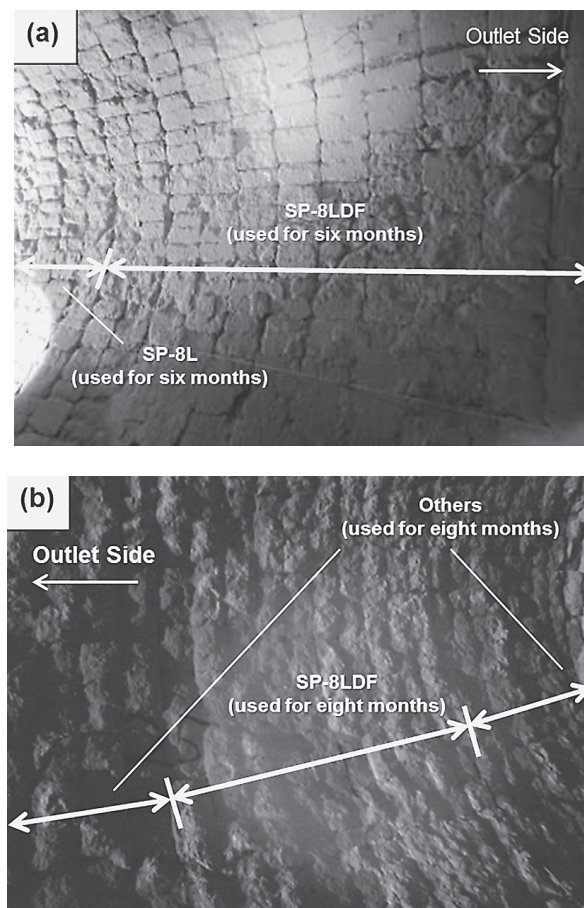


Fig.18 Appearance of SP-8LDF used at (a)  $L/D = 9.9 \sim 10.9$  for six months in an NSP kiln and at (b)  $L/D = 4.6 \sim 5.0$  for eight months in a SP kiln.

The refractories were damaged severely by mechanical spalling. The standard SP-8L used at the upper side of  $L/D = 10.9 \sim 11.5$  for 6 months, was severely worn by mechanical spalling. However SP-8LDF, with low torsional rigidity and good stress relaxation, showed no peeling off and gave good durability.

Figure 18(b) shows the appearance of SP-8LDF used at the position of  $L/D = 4.6 \sim 5.0$  near the tire area in an SP kiln after 8 months of service. In this area, mechanical stress repeatedly attacks refractories, but SP-8LDF achieved longer durability.

## 6. Summary

We evaluated cement kiln refractories using

た標準品SP-8Lは目地切れが多発し剥離損傷もみられる状況だったが、ねじり剛性率が低く、応力緩和性の高い「SP-8LDF」を適用した部分はほぼ平滑に損耗しており、良好な耐用だった。また、Fig.18(b)に大径SPセメントキルンの $L/D = 4.6 \sim 5.0$ の支点部付近に「SP-8LDF」を適用し約8ヶ月間使用後の炉内状況を示す。該部は従来から機械的応力の影響でれんがの圧壊が繰り返されていた部位であったが、「SP-8LDF」を適用して以降は損傷が改善され安定耐用を実現した。

## 6. まとめ

当社セメントキルン用れんがについて、従来の評価項目に加え、機械的特性に着目して評価し、実機に適用した結果、狙い通りの耐用性向上が得られた。

- (1) 熱間ねじり試験によるねじり剛性率とトルク緩和曲線で変形能と応力緩和性を評価した。ねじり剛性率が低いものは変形能が高いと考えた。
- (2) ねじり剛性率が低く、応力緩和性の高い「SP-8DF」を冷却帯に適用した。その結果、従来品よりも剥離損傷が低減し、1運転（3ヶ月）から2運転（6ヶ月）へ耐用性が大幅に改善した。
- (3) ねじり剛性率が低く、応力緩和性の高い「SP-8LDF」を遷移帯に適用した。その結果、従来品よりも剥離損傷が低減した。

not only conventional physical characteristics but also thermos-mechanical characteristics. We improved the cement kiln refractory materials with new evaluation methods and applied them to the zones of a cement kiln where refractories were severely damaged by mechanical spalling. They achieved much longer service-life.

- (1) The deformability and stress relaxation of refractories were evaluated using torsional rigidity and torque relaxation curves from a torsional test. Lower torsional rigidity is considered to have shown more deformability.
- (2) SP-8DF, with low torsional rigidity and high stress relaxation, was applied to cooling zone. The damage was significantly decreased compared to conventional products and the service-life was improved from 1 campaign (3 months) to 2 campaigns (6 months).
- (3) SP-8LDF, with low torsional rigidity and high stress relaxation, was applied to the transition zone. The damage was much less than the conventional products.

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