Microstructural stability of Co-Re-Cr-Ta-C alloy strengthened by TaC precipitates

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Microstructural stability of Co-Re-Cr-Ta-C alloys strengthened by TaC precipitates

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Ralph Gilles and Lukas Karge *(TU Munich, Garching, DE)* | Pavel Stunz and Přemysl Beran *(NPI, Rez near Prague, CZ)*

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Co-Re-based alloys: for high temperature gas turbine applications

• Present Status of Co-Re alloy development
  • alloy development concept

• Microstructural stability
  • Co-matrix transformation: $\varepsilon \Leftrightarrow \gamma$
  • TaC precipitates

• Creep properties

• Outlook
Co-Re alloy concept

Melting range: Metallic Alloys “Beyond Ni-Base Superalloys”

Co-Re-Cr alloy melting range
~ 1523° to 1575°C

Considerably higher Melting Range than Ni-superalloys
Oxidation resistance: Co-Re-Cr-Si system

Good oxidation resistance up to 1100°C
Alloy strengthening: by carbides

Fine dispersion of carbides in alloys with Cr, Ta and C addition

Dislocations interacting with TaC precipitates

Carbides provide effective strengthening in Co-Re-Cr-Ta-C alloys
Design considerations: tcp phase

- Fine dispersion of $\sigma$ phase in alloys can be achieved
- Can provide effective strengthening with high ductility

$> 20\% \text{ Cr addition stabilizes } \sigma \text{ phase (Cr}_2\text{Re}_3)$
Design considerations: grain boundaries in polycrystalline alloys

Polycrystalline Co-Re-Cr alloy is stronger than SX Ni-superalloys

Boron addition mitigates environment embrittlement and improves ductility

**Graph:**
- **Tensile Test at room temperature**
  - **X-axis:** Strain (%)
  - **Y-axis:** Stress (MPa)
  - **Lines:**
    - Co-17Re-23Cr
    - Co-17Re-23Cr + 500 wt.ppm B

**Table:**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Density (ρ) g/cc</th>
<th>UTS (σ) MPa</th>
<th>Specific Strength (σ/ρ)</th>
<th>Ductility (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-17Re-23Cr + 500B</td>
<td>11.5</td>
<td>1276</td>
<td>110.9</td>
<td>20.3</td>
</tr>
<tr>
<td>CMSX4</td>
<td>8.7</td>
<td>894</td>
<td>102.7</td>
<td>22</td>
</tr>
</tbody>
</table>
Co-Re-based alloys: for high temperature gas turbine applications

- Present Status of Co-Re alloy development
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- Microstructural stability
  - Co-matrix transformation: \( \varepsilon \Leftrightarrow \gamma \)
  - TaC precipitates

- Creep properties

- Outlook
Microstructural stability:

- In order to study TaC precipitates Co-Re-Ta-C alloys investigated [C/Ta – 0.5y to 1.0y]
- This ensured no σ phase and Cr-carbides in the alloy
- Study – TaC morphology and stability and Co matrix transformation
- Binary TaC is stable to very high temperatures but in Co-Re system its stability not investigated
- Binary TaC is not a stoichiometric compound and exists in wide composition range
- Other Ta-carbides can be also stable in this composition range
Co matrix transformation: $\epsilon$ (hcp) $\Leftrightarrow \gamma$ (fcc)

Transformation:

On heating – Co (hcp) $\rightarrow$ SF + MT $\rightarrow$ Co (fcc)

On cooling – Co (fcc) $\rightarrow$ SF + MT $\rightarrow$ Co (hcp)

Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C

Lower C/Ta ratio in the alloy higher Transformed region

Co-17Re-1.2Ta-0.6C (0.5y) alloy ST + 1100°C
Co matrix transformation: $\varepsilon$ (hcp) $\leftrightarrow$ $\gamma$ (fcc)

EBSD

Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C

Transformed region is a mixture of $\varepsilon$ + $\gamma$ phases
**Co matrix transformation:** \( \varepsilon \) (hcp) \( \rightleftharpoons \) \( \gamma \) (fcc)

- **EBSD**
  - Transform region I
  - Transform region II

- **Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C**

- **Transformation**
  - Region I (\( \varepsilon \) Co + SF and MT)
  - Region II (\( \varepsilon \) Co + \( \gamma \) Co)

**Transformation occurs through SF and MT formation**
Co matrix transformation: $\varepsilon$ (hcp) $\Leftrightarrow$ $\gamma$ (fcc)

**EDS**

Co-17Re-1.2Ta-0.8C (0.7y) alloy ST + 1000°C

**Microstructural Stability**

**Transformed regions** are rich in Co and **Un-transformed regions** rich in Re
**Co matrix transformation:** $\varepsilon$ (hcp) $\Leftrightarrow$ $\gamma$ (fcc)

**In-situ neutron diffraction**

- $\gamma$ Co (200) peak evolution during heating and cooling
- Left side alloys with Cr and right side alloys without Cr
- $\gamma$ Co retained to RT in alloys without Cr
- Metastable $\gamma$ Co transform to stable $\varepsilon$ Co on heating (see hold at 900°C)
- Allotropic $\varepsilon \Leftrightarrow \gamma$ Co transformation occurs above 1100°C.

**\(\gamma\) Co (200) peak**

- C/Ta -0.9
- + 15Cr
- + 5Cr
- C/Ta -0.5
Co matrix transformation: $\varepsilon$ (hcp) $\Leftrightarrow$ $\gamma$ (fcc)

- Co has allotropic transformation from $\varepsilon$ (hcp) to $\gamma$ (fcc) phase.
- In pure Co it is at 417°C.
- The transformation is composition dependent.
- In Co-Re alloys the transformation temperature is high > 1000°C.
TaC precipitates: morphology and stability

Microstructural Stability

Low C alloys:
100% Transformed Matrix

Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C
High C alloys:
Large Cuboidal TaC

Co-17Re-1.2Ta-0.6C (0.5y) alloy ST + 1100°C

Low C alloys:
100% Transformed Matrix

High C alloys:
Large Cuboidal TaC
A wide variety of TaC precipitate morphology is possible.

A very fine dispersion of TaC (less than 10 nm spherical particles)
**TaC precipitates: morphology and stability**

A wide variety of TaC precipitate morphology is possible.

Short and long needle-like TaC precipitates.
A wide variety of TaC precipitate morphology is possible

Relatively coarse and also lamellar TaC precipitates
Co matrix transformation affects TaC precipitates
Some Recent Results: synchrotron measurements

In-situ diffraction show TaC precipitates are stable up to 1200°C

Long term microstructural stability during application in gas turbine is very important.

Some Recent Results: neutron measurements

In-situ SANS show TaC precipitates remain fine (< 100 nm)

Creep Results: compression creep

- only few precipitates
- fine precipitates

TaC precipitates provide creep strengthening
Creep Results: compression creep

- High C alloys had higher amounts of TaC phase
- Low C alloys had finer TaC precipitates

TaC precipitates morphology and size can be tailored through heat treatment
Summary & Outlook

- Co-Re alloys show great potential for development and in-situ measurements with synchrotron and neutron provide tools for understanding the alloy system.
- TaC precipitates are effective in providing high temperature strengthening.
- Co matrix transformation can be exploited in tailoring microstructure and precipitate dispersion, however, the transformation temperature should be pushed to temperature higher than the envisaged application.

Outlook:

1. Directional solidification and single crystal growth studies are essential for blade application: *initial studies indicate there are significant challenges posed by the Co-matrix allotropic transformation.*

2. Oxidation resistance of Co-Re alloys must be improved to higher temperature: *investigation jointly with Universität Siegen is in progress.*
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