Thermomechanical Damage Evolution
in Plasma Facing Materials

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Abstract

Thermomechanical damage can be described as any process or process outcome which changes the nature of a material or engineering component to the extent which renders it unusable for its original intended purpose. A wide variety of damage phenomena occur during high temperature operation of a number of important structures such as atmospheric re-entry vehicles, rockets, and fusion and/or fission reactor systems. Each of the aforementioned devices experiences a unique damage environment which must first be fully understood and properly quantified in order to improve the safety, reliability, and cost effectiveness of the service it provides. It is in this spirit of improvement that damage models and experimental systems are developed for the primary purpose of providing end users with materials and engineering systems of superior reliability even under the most extreme conditions.

Introduction

- Materials systems are inherently limited in their capacity to resist the damaging effects of high temperature environments.
- Incumbent upon the current generation of researchers to develop new methods for improving materials performance.
- Next generation devices such as ion propulsion systems, fusion and fission reactors, rocket technology etc will rely heavily on the materials which comprise their core systems.

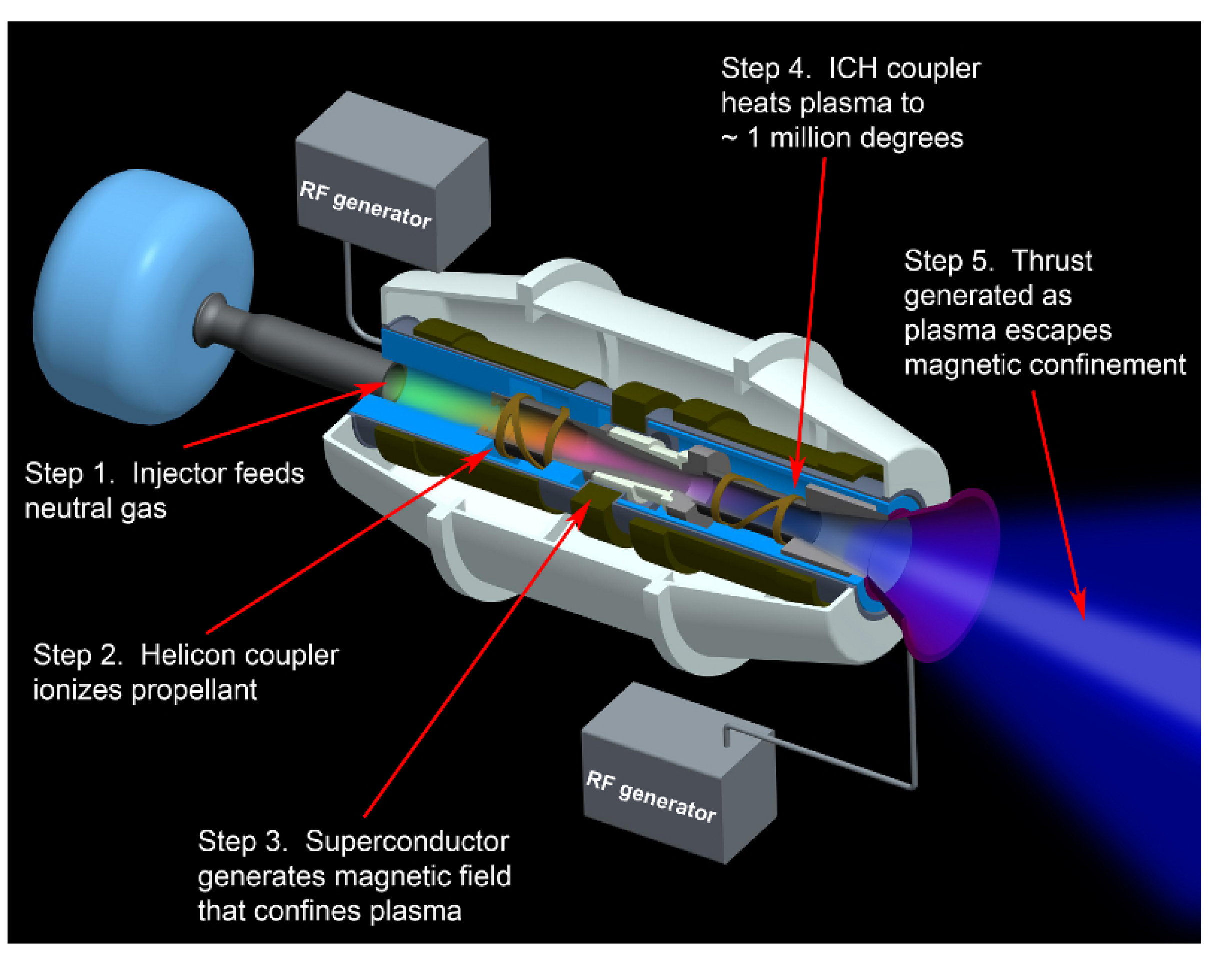

Figure 1: VASIMIR electric propulsion system, will make for some of the harshest material conditions.

Main Objectives

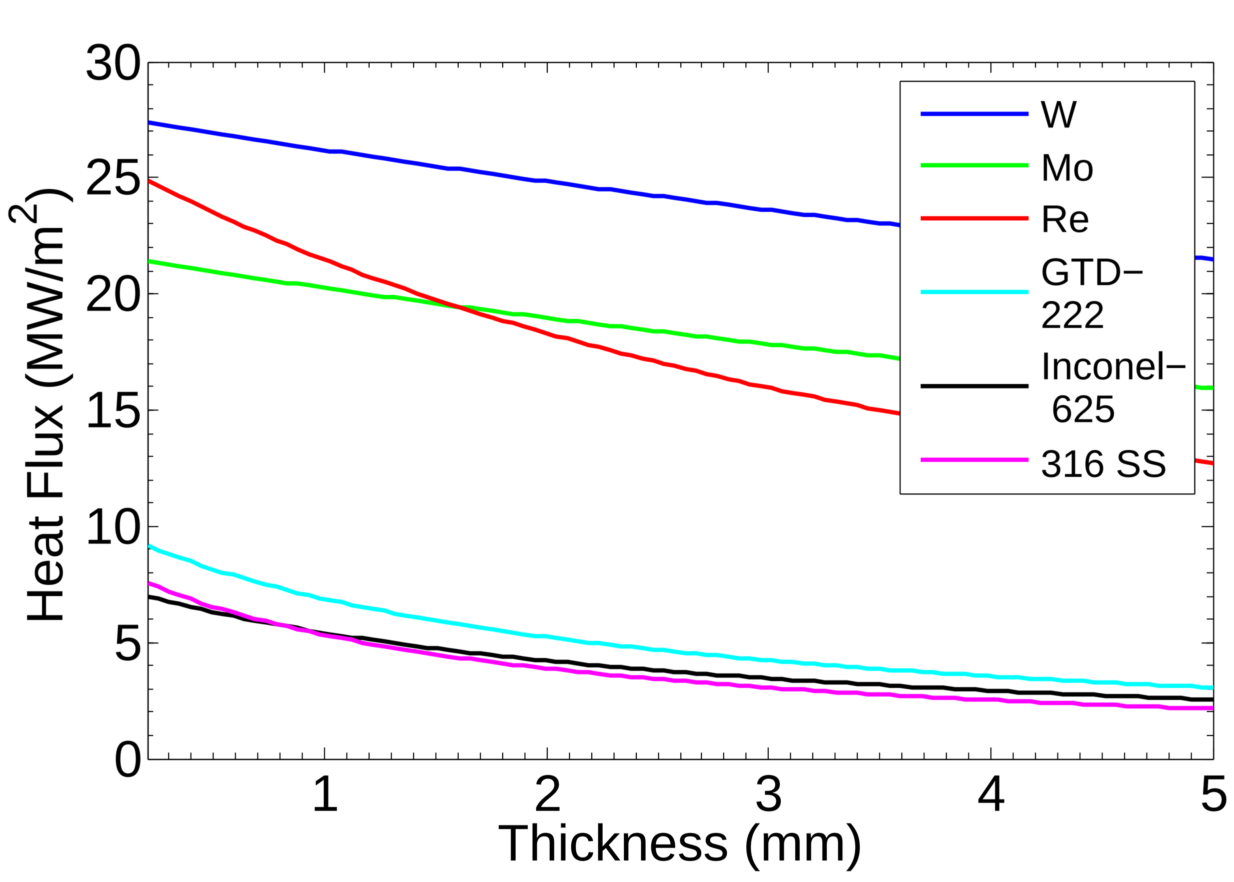

Figure 2: Comparison of different ultra high temperature metals, describes the max allowable heat flux for a material to operate at half its melting temperature under steady state conditions, convective heat transfer coefficient taken to be 10 kW/m^{2}K, cooling water temperature is 300 K, from the figure it is clear that W forms an ideal candidate material even when compared to other refractory metals and superalloys.

- objective 1: Identify and develop a materials system capable of extended safe operation in a high stress/high temperature environment.
- objective 2: Develop a testing facility capable of simulating the extreme environments seen by fusion reactors and electric propulsion devices
- objective 3: Implement a materials characterization plan to measure and quantify the level of damage seen by the material

Research Impact

The identified and developed materials system will have the potential to revolutionize the high temperature materials market by introducing a new set of design parameters previously thought unattainable in the coatings industry. Novel design parameters will consist of an ability to tune mechanical properties via selection of surface geometry.

Experimental Apparatus

- Hefty is an experimental system dedicated to testing the durability of materials in extreme heat flux situations.
- A commercial plasma gun (arc-jet) is used to impart a heat loads onto a cooled sample.
- Application of heat flux generates thermal stresses within the sample, at high temperatures stiff metals such as tungsten take on a much softer nature and are able to deform and flow with ease.

Figure 3: View of plasma impacting a W sample in the Hefty facility

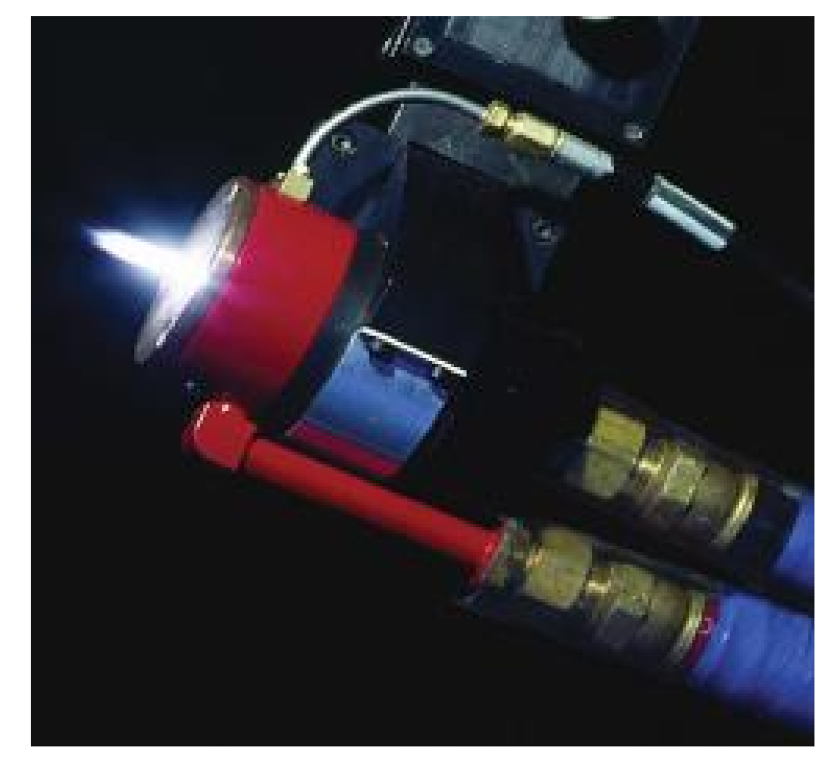

Figure 4: Praxair SG-100 plasma gun (arc-jet), used as a heat source

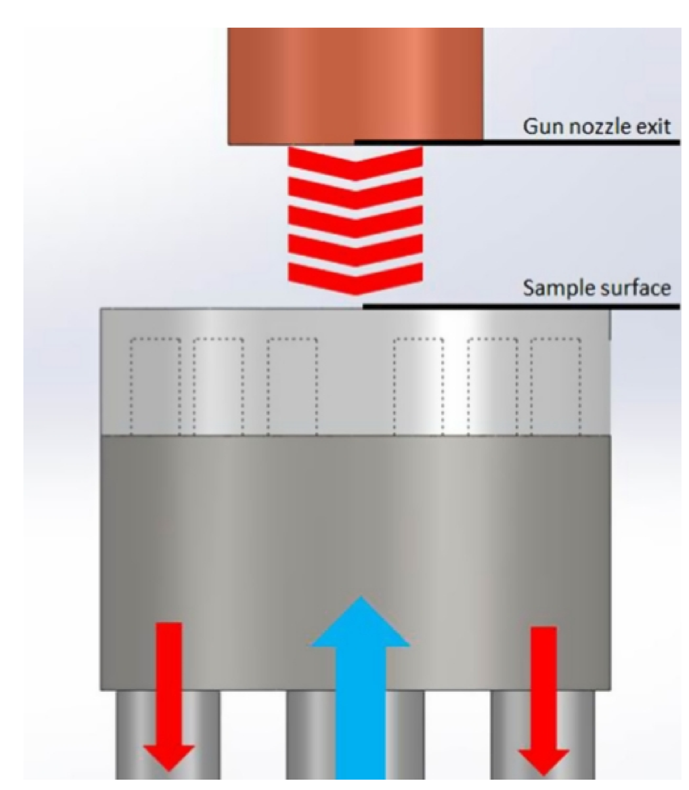

Figure 5: Sample is exposed to plasma while being simultaneously cooled, provides for the ability to study materials phenomena in more true to life scenarios.

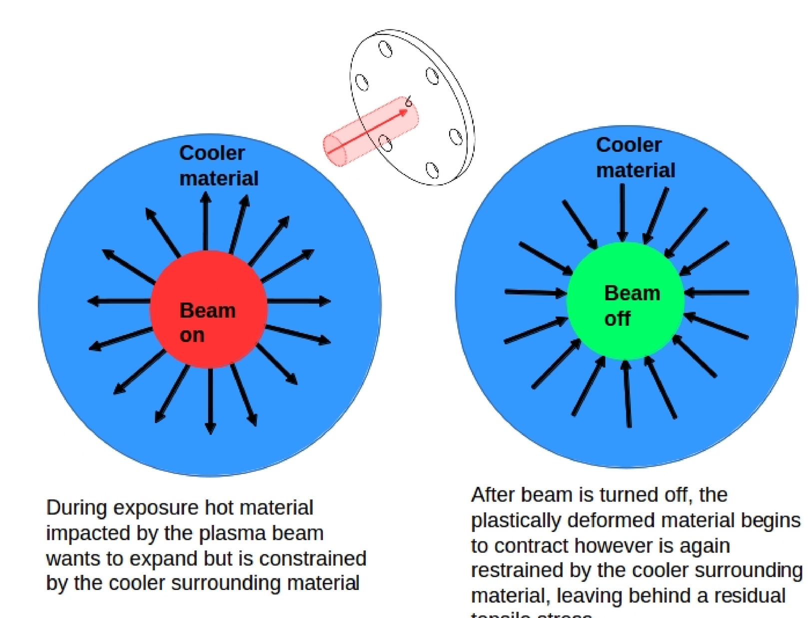

Figure 6: Illustration of material state during high heat flux testing.

- Pulsed operation of the plasma gun (on/off cycles) provides an opportunity to study thermal fatigue.
- Materials tested under these types of conditions generally fail earlier than those under the same constant load.

Results

- Initial plasma exposure results indicate that large thermal stresses are generated within the material.
- Indicated via fracture of flat tungsten samples.

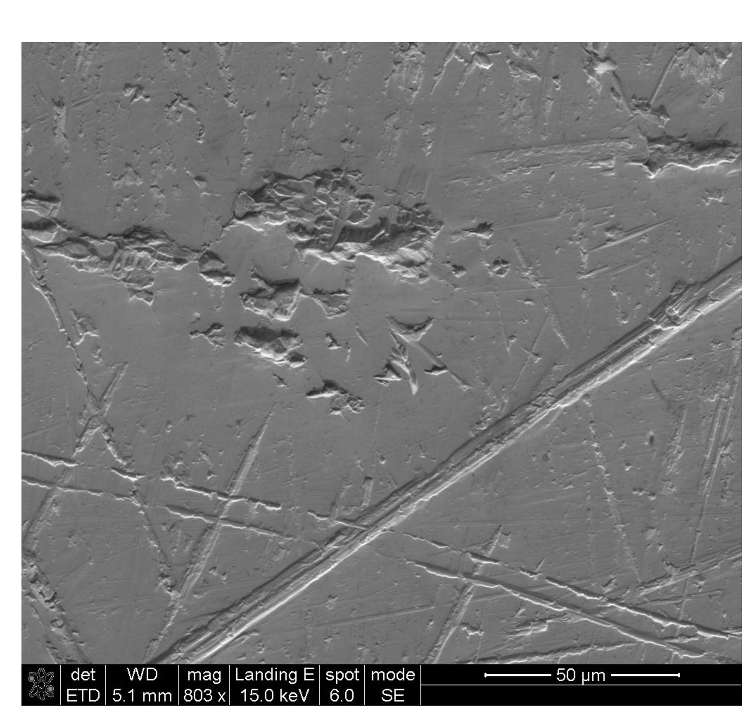

Figure 7: Flat (relatively) tungsten surface before testing.

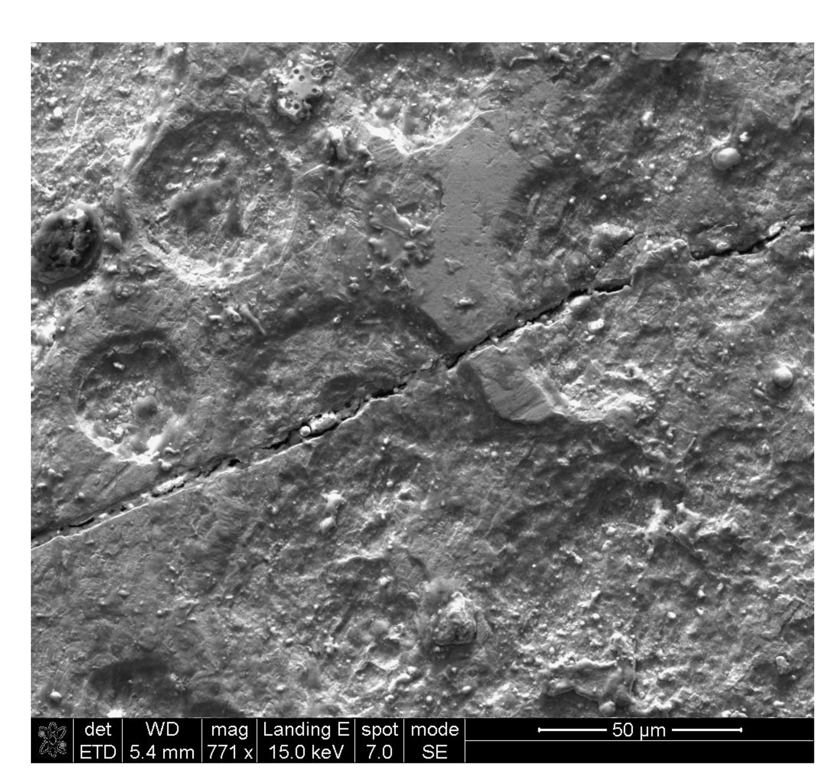

Figure 8: Fractured tungsten surface after testing.

- Characterization of planar materials exposed to plasma irradiation indicate that there is permanent deformation of the surface.
- This type of permanent distortion can be a source of stress and eventual failure of the material.
- Materials design efforts benefit from such testing by providing suitable starting points for improvement via design schemes such as alloying, alteration of the surface architecture etc.

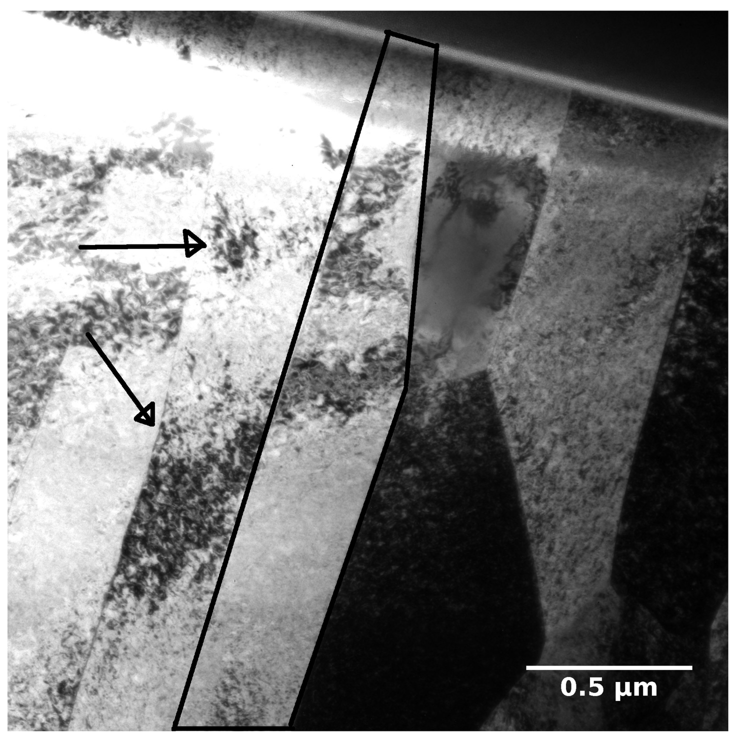

Figure 9: W microstructure, dark regions (arrows) indicate areas of high dislocation density.

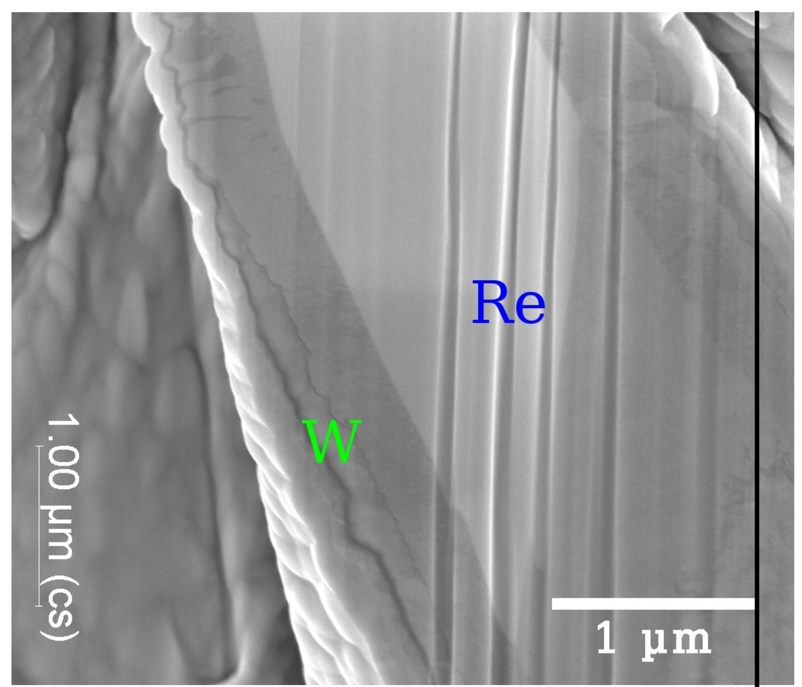

Figure 10: Cross-section of micropillar.

Although it has been shown experimentally that micro-architected materials posses superior qualities in terms of mechanical resistance to thermal damage than their planar counterparts effective modeling of the material is key to development of these systems. This modeling effort aims to capture natural materials deformation phenomena such as the accumulation on dislocations at grain boundary walls, and the subsequent evolution of micro-structure under a variety of combinations of temperature and stress.

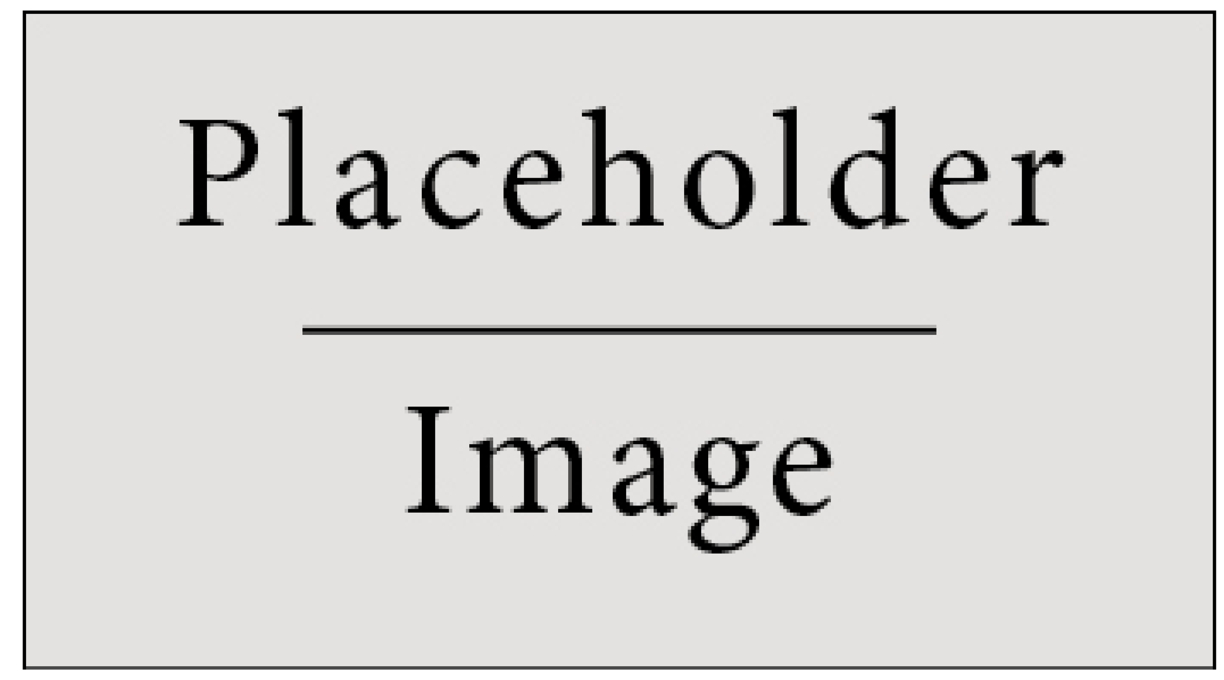

Figure 11: Figure caption

Conclusions

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Forthcoming Research

Possible future research
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Acknowledgements

Acknowledgements