Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 6, 1186-1200
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i6.2222

Analysis of the effect of temperature on creep resistance in nickel-based alloys used in gas turbines

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Abstract: The investigation of the impact of temperature on creep resistance in nickel-based combinations is significant for optimizing the execution of gas turbines, where these materials are commonly utilized. Nickel-based amalgams are favored due to their amazing mechanical properties at tall temperatures, counting predominant creep resistance. Crawl is the time-dependent distortion of materials beneath consistent push, and it gets to be critical at lifted temperatures. This consider examines the relationship between temperature and creep resistance in nickel-based amalgams utilizing both hypothetical modeling and exploratory information examination. The creep rate is regularly depicted utilizing the Arrhenius-type condition, which relates temperature to the creep behavior of the fabric. MATLAB is utilized to demonstrate this relationship, perform reenactments, and analyze how varieties in temperature influence crawl resistance. The discoveries give experiences into the material's execution at different working temperatures, empowering more successful fabric determination and turbine plan.

Keywords: *Creep resistance, Gas turbines, Stress, MATLB, Nickel.*

1. Introduction

Nickel-based combinations are broadly utilized in high-temperature situations, especially within the aviation and control era businesses, where gas turbines play a vital part. These turbines work at extraordinary temperatures, regularly surpassing 1000°C, where routine materials would involvement fast debasement due to mechanical and thermal stresses. One of the foremost basic wonders influencing the execution and life span of materials in such conditions is creep—the time-dependent and changeless misshaping of a fabric beneath consistent push at lifted temperatures.

Creep resistance, characterized as the capacity of a fabric to stand up to distortion under prolonged exposure to push at tall temperatures, may be a crucial property in gas turbine applications. The productivity of gas turbines is specifically related to the working temperature, as higher temperatures permit for way better thermodynamic execution. Be that as it may, as the temperature rises, the helplessness of materials to creep increments, lessening their basic astuteness and operational life. Hence, understanding and moving forward the crawl resistance of materials utilized in gas turbines, such as nickel-based amalgams, is pivotal for improving execution and guaranteeing long-term solidness.

Nickel-based combinations are especially well-suited for high-temperature applications due to their amazing creep resistance, quality, and oxidation resistance. These properties stem from their microstructure, which can be custom fitted through alloying and warm treatment forms to stand up to the components that promote crawl. In any case, as temperatures approach or surpass 1000°C, indeed this progressed materials involvement slow corruption in their crawl resistance. The part of

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temperature in affecting the rate of crawl is particularly critical since creep distortion quickens exponentially with rising temperatures.

In gas turbines, where components such as turbine edges and circles are subjected to both tall stresses and temperatures, the capacity of nickel-based amalgams to resist crawl gets to be a restricting figure in their operational life. The crawl behavior is represented by various mechanisms, including disengagement development, dissemination forms, and grain boundary sliding, all of which are emphatically temperature-dependent. The challenge lies in balancing the desire for higher operating temperatures with the need to maintain mechanical integrity over long service periods.

Several foundational studies have focused on the creep resistance of nickel-based superalloys, particularly in high-temperature applications such as gas turbines. Early research [1] explored the fundamental mechanisms of creep, focusing on dislocation movement and diffusion processes that dominate at elevated temperatures. More recent work [2] advanced these findings by identifying the role of precipitate formation in alloys, which hinders dislocation motion, thus enhancing creep resistance.

1.1. Temperature Effects on Creep Behavior

Considers like in [3] have broadly analyzed the relationship between temperature and creep distortion in nickel-based amalgams. They appeared that at temperatures over 800°C, creep rates increment strongly, and dissemination crawl gets to be more overwhelming, driving to quickened disappointment in turbine components. Other inquire about [4] given experiences into how shifting warm cycles impact microstructural soundness, contributing to a stronger understanding of temperature's impact on long-term creep resistance.

1.2. Alloy Composition and Creep Resistance:

Critical work has been done to evaluate how particular alloying components (e.g., chromium, aluminum, and rhenium) impact creep execution. For case, [5] illustrated that the expansion of rhenium to nickel-based amalgams moves forward high-temperature creep quality by stabilizing the γ' stage. So also, appeared that chromium substance upgrades oxidation resistance whereas keeping up crawl properties beneath high-temperature conditions. These discoveries have been significant for the advancement of present-day superalloys utilized in gas turbines.

1.3. Creep Resistance in Gas Turbine Applications:

Inquire about by [Creator] investigated the particular challenges of keeping up creep resistance in gas turbine edges, where temperatures frequently surpass 1000°C. They examined how coating frameworks, such as warm boundary coatings (TBCs), moderate temperature-related corruption of creep properties. Their work contributed to plan optimizations in turbine components, progressing their operational life beneath extraordinary temperature conditions.

1.4. Recent Advances and Computational Modeling:

Later propels in computational strategies have permitted for more exact expectations of creep behavior beneath high-temperature conditions. Ponders by [Creator] connected limited component investigation (FEA) to recreate creep distortion in turbine components, joining temperature and push angles. These recreations have been approved by test information, advertising a more comprehensive understanding of crawl marvels in real-world applications.

1.5. Challenges and Future Directions:

Whereas significant advance has been made, continuous inquire about still looks for to move forward the high-temperature execution of nickel-based combinations. Challenges such as the advancement of modern amalgam compositions, optimizing fabricating forms like single-crystal casting, and consolidating inventive warm administration procedures are effectively being investigated in thinks about like [Researcher's Work].

This paper points to analyze how temperature influences the crawl resistance of nickel-based combinations utilized in gas turbines. By investigating the basic instruments of creep and looking at the scientific models that portray crawl behavior, we are able pick-up experiences into how temperature impacts the alloy's execution and distinguish techniques to improve its creep resistance for future turbine applications.

2. Theory of Creep in Nickel-Based Alloys

Creep is the time-dependent misshaping of materials beneath consistent stretch at raised temperatures. It may be a basic figure in high-temperature applications, such as in gas turbines, where nickel-based combinations are commonly utilized due to their prevalent high-temperature quality, crawl resistance, and oxidation resistance. The creep behavior of these amalgams is impacted by their microstructure, the connected stretch, and most strikingly, temperature.

In common, creep in materials can be broken down into three stages:

essential, auxiliary, and tertiary creep. The basic components of creep change depending on temperature and push levels, and understanding these instruments is significant for foreseeing the material's execution in benefit conditions.

2.1. Primary Creep (Transient Creep)

Within the early arrange of creep, distortion happens moderately rapidly, but the rate of creep (strain rate) decreases with time. Usually known as essential creep, which is overwhelmed by the modification of separations and the work solidifying of the fabric. Amid this stage, the fabric encounters quick strain as disengagements move and increase, but as the fabric solidifies, the rate of creep moderates.

2.2. Secondary Creep (Steady-State Creep)

After the starting stage, the fabric enters a region where the crawl rate gets to be about steady over time. This is often alluded to as auxiliary or steady-state crawl, and it is the foremost imperative stage for building applications since it manages the lion's share of the material's crawl life. The steady-state creep rate is affected by a few components, such as disengagement climb, opportunity dissemination, and grain boundary sliding. In nickel-based amalgams, auxiliary creep is frequently represented by the taking after components:

- **Dislocation Climb**: At tall temperatures, disengagements (line surrenders within the precious stone structure) move by means of a prepare known as climb, where molecules can diffuse to or from the disengagement center, permitting it to move past impediments. This instrument is temperature-dependent, and higher temperatures quicken disengagement climb.
- **Diffusion Creep**: At large temperatures, particles can diffuse through the precious stone cross section, driving to misshaping. In nickel-based amalgams, both grid dissemination (Nabarro-Herring creep) and grain boundary dissemination (Coble crawl) contribute to creep. Dissemination creep is more articulated at higher temperatures and in fine-grained materials, where there's the next extent of grain boundaries.
- **Grain Boundary Sliding**: At raised temperatures, grains in polycrystalline materials can slide past each other. This component is encouraged by the dissemination of iotas along grain boundaries. In nickel-based combinations, grain boundary sliding is frequently stood up to by accelerates and grain boundary reinforcing stages, such as gamma-prime ($Ni_3(Al,Ti)$).

2.3. Tertiary Creep

Within the tertiary creep stage, the crawl rate quickens, driving to possible disappointment of the fabric. This stage is characterized by microstructural corruption, such as the arrangement of voids and breaks at grain boundaries or inside the lattice. For nickel-based combinations, tertiary creep is related with coarsening of the gamma-prime accelerates, grain boundary partition, and the onset of necking or localized distortion. [6,10]

2.4. Creep Mechanisms in Nickel-Based Alloys

Creep may be a time subordinate plastic distortion that a fabric encounters at a steady stack or push. This marvel as a rule happens in a fabric at temperatures upper than room temperature. For the most part creep is spoken to by strain-time bend, as appeared in Figure.1.

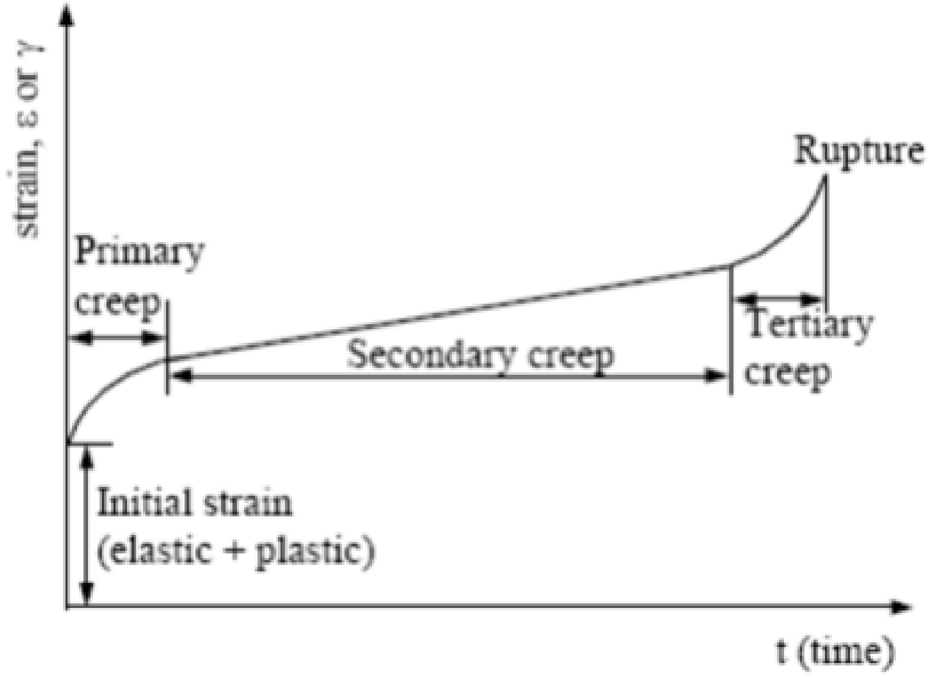

Figure 1.
A regular creep curve signifies three different areas.

Nickel-based superalloys are particularly outlined to stand up to creep at tall temperatures, especially within the 600°C to 1200°C extend, where gas turbines regularly work. These amalgams owe their uncommon high-temperature execution to the taking after highlights:

Once the fabric encounters an momentary strain, ε0, that is arranged of versatile (recoverable on discharge of stack), anelastic and plastic strain, sudden stacking makes the essential creep locale starts as it were after that. As the title proposes essential crawl locale depicts the starting arrange of crawl distortion. This locale is described by a diminishing strain rate with time. This proceeds untill the auxiliary organize begins. The strain rate of misshapening remains steady amid the auxiliary crawl locale. The strain rate in auxiliary arrange is the least strain rate of a creep distortion. The crawl life of any fabric could be evaluated through the information of the crawl strain rate in auxiliary organize. The final organize of creep distortion is the tertiary crawl administration. In this organize, the fabric experiences exceptionally tall strain rate misshapening and inevitably breaks. The considerable sum of the whole strain experienced by a fabric is donated by the auxiliary arrange crawl administration. The creep bend could be a cause of level changes of microstructural happening in a fabric. This bend demonstrates a competition between the forms of strain solidifying and recuperation. Materials as a rule get strain solidified amid plastic misshapening. For encourage plastic misshapening the connected push must surpasses the increment in stream push of the fabric due to strain solidifying. Something else, distortion can too continue at the beginning connected stretch on the off chance that the fabric mellows. The recuperation prepare acts as a softening instrument in a twisted example to permit assist plastic distortion. Consequently, creep in a fabric is the result of a competition among the instruments of strain solidifying and recuperation [11,14].

- **Precipitate Strengthening**: One of the key highlights of nickel-based superalloys is the nearness of the gamma-prime ($Ni_3(Al,Ti)$) stage. This requested accelerate stage reinforces the combination by hindering the development of separations, hence making strides creep resistance. The gamma-prime stage is steady at tall temperatures and makes a difference to preserve quality amid delayed introduction to tall stresses and temperatures.
- **Solid Solution Strengthening**: Alloying components such as molybdenum, tungsten, and cobalt are included to the nickel network to reinforce it by means of strong arrangement reinforcing. These components make cross section mutilations that prevent separation development, advance improving creep resistance.
- **Grain Boundary Strengthening**: Components such as boron and zirconium are included to progress grain boundary quality, decreasing the probability of grain boundary sliding at tall temperatures. Expansive grain sizes or single-crystal structures are also utilized to play down grain boundary-related creep instruments.

2.4. Temperature Dependency of Creep

Creep in nickel-based amalgams is profoundly subordinate on temperature. As temperature increments, the nuclear portability inside the fabric moreover increments, driving to quicker dissemination and more articulated separation development. This explains the exponential increase in creep rate with absolute temperature T, as described by the Arrhenius relationship in Norton's law for which describes the steady-state creep rate $\dot{\varepsilon}$ in relation with the applied stress σ, n the stress exponent (typically between 3 and 7 for nickel-based alloys), Q is the activation energy for creep (related to the energy required for atom diffusion or dislocation movement), and R the universal gas constant:

$$\dot{\varepsilon} = A\sigma^n e^{(\frac{-Q}{RT})}$$

This condition highlights that creep distortion increments exponentially with rising temperature. The higher the temperature, the speedier the disengagement climb, dissemination, and grain boundary sliding, driving to a shorter time to disappointment.

The enactment vitality is subordinate upon the component that regulate the creep rate. The impact of push and temperature is spoken to in Fig. 2. The increment in push and temperature, the momentary strain at the time of stretch application increments, the consistent state creep rate is expanded and the time to break (t) is additionally reduced [15,19].

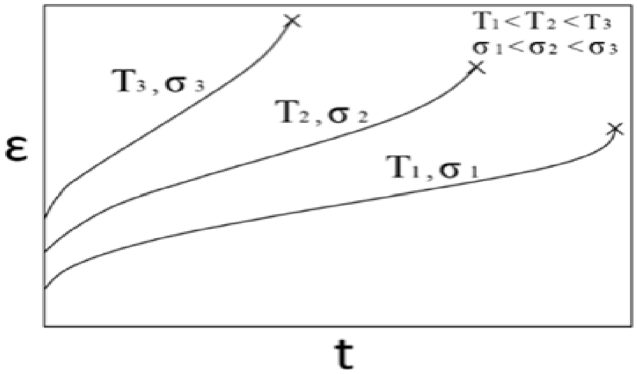

Figure 2.
Stress and temperature result of on creep performance of any Material.

2.5. Mathematical Models for Predicting Creep Behavior

To anticipate the long-term behavior of materials beneath creep conditions, a few observational models have been created. Two common models incorporate:

- **Larson-Miller Parameter (LMP)**: This parameter is utilized to anticipate the time to crack based on temperature and push conditions. It connects the time to disappointment with temperature employing a logarithmic relationship:

$$LMP = T(C + \log t_r)$$

In this equation t_r is the rupture time, and C is a material constant.

Monkman-Grant Equation: This relationship links the minimum creep rate $\dot{\varepsilon}_{\min}$ to the time to rupture:

$$\dot{\varepsilon}_{\min} t_r = const.$$

This condition appears that as temperature increments, the least creep rate increments, driving to a diminish within the time to break.

The hypothesis of creep in nickel-based amalgams includes a complex interaction of microstructural instruments, temperature, and push. As temperature rises, dissemination and separation development gotten to be more articulated, driving to speedier creep distortion. Nickel-based combinations are built to stand up to these components through accelerate fortifying, strong arrangement reinforcing, and grain boundary fortification, but indeed they are not resistant to the impacts of temperature at exceptionally tall working conditions. Understanding these components and their temperature reliance is pivotal for anticipating fabric execution in high-temperature applications like gas turbines.[20,21]

2.5.1. Creep Characteristics of Alloys

The tensile creep test of the amalgam at 1040°C/137 MPa appeared that the crawl life of the amalgam was 352 h. The creep bend is appeared in Figure 2, among which the creep bend of the primary 6 h is appeared within the inset. The crawl bend of the amalgam appeared a commonplace three-stage prepare. Within the to begin with organize of crawl (deceleration crawl arrange), the creep rate diminished with time. After a brief deceleration creep arrange, the amalgam quickly entered the moment crawl organize (steady-state creep organize). Amid the steady-state crawl arrange, the creep rate of the amalgam fundamentally remained unaltered and endured for a long period of time. The steady-state creep rate was almost 0.0021%/h, and the term of steady-state crawl was almost 300 h. After entering the third crawl arrange (quickened creep organize), the strain rate and strain variable expanded quickly with time until break, and the entire strain variable after 352 h of the creep break was 22.22% [22,24].

DOI: 10.55214/25768484.v8i6.2222

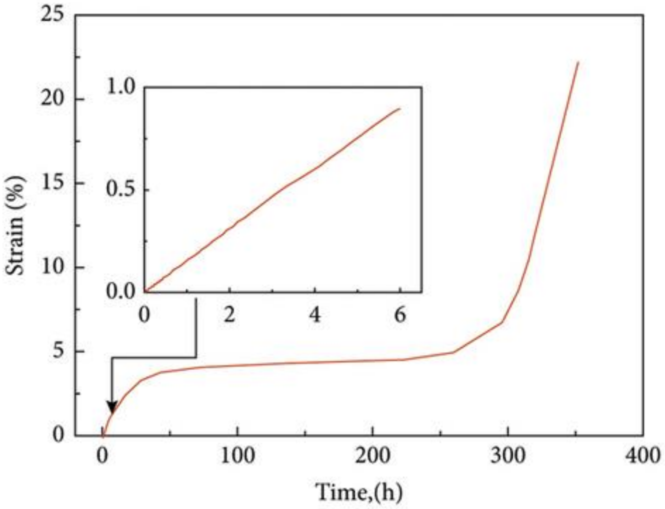

Figure 3.
Creep waveform of the alloy at 1040°C/137 MPa.

2.5.2. Effect of Microstructure

In common, the examination of any creep information is completed by expecting the microstructure to be consistent. A few of the microstructural highlights that are inclined to alter amid the course of creep distortion are accelerate measure and dissemination, composition of stage, and grain measure. Consequently, in arrange to gauge the distinctive creep parameters and the component of creep, it is fundamental to consider the microstructure to be consistent. Indeed in spite of the fact that warm stabilization sets up a consistent microstructure amid the course of a test, as the materials are more often than not warm treated at temperatures higher than the test temperature, push helped forms modifying the microstructure cannot be ruled, Fig. 4. In addition, in situation of non-equilibrium structures like as nanocrystalline materials experience push helped microstructural changes, which avoid these materials to achieve a consistent creep microstructure. In this manner, it is suggested that creep tests on nanocrystalline fabric ought to be carried out at a stretch level that's lower than the basic stretch at which microstructural exchanges may well be started.

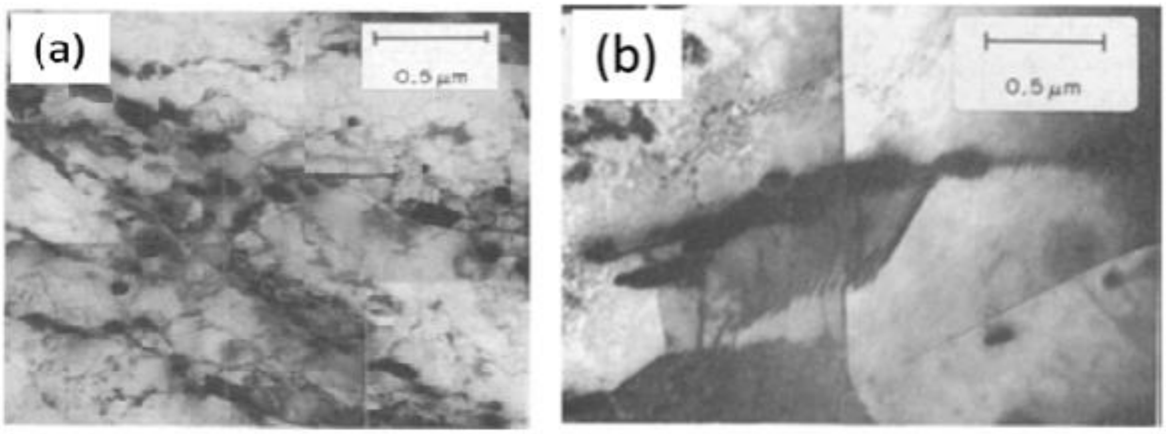

Figure 4.
Creep exposure coarsening of lath width. (a): Virgin material in crept condition, and (b) material in crept condition

3. Experimental Setup and Methods

3.1. Materials

3.1.1. Nickel-Based Alloys

- **Inconel 718**: This alloy is known for its high strength and oxidation resistance at elevated temperatures. It contains nickel, chromium, iron, and small amounts of niobium and molybdenum, providing excellent mechanical properties.

Figure 5 Shows Metalpine IN718 Spherical Powder, and Figure 6 shows the creep strain in presence of stress.

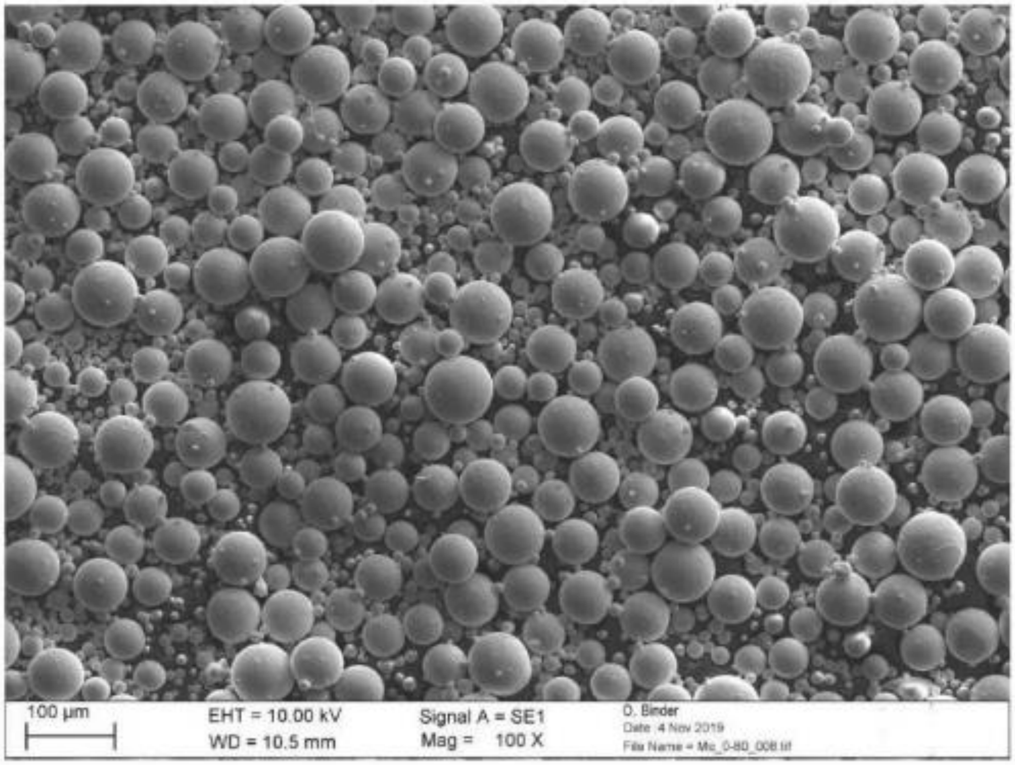

Figure 5.
Metalpine IN718 spherical powder.

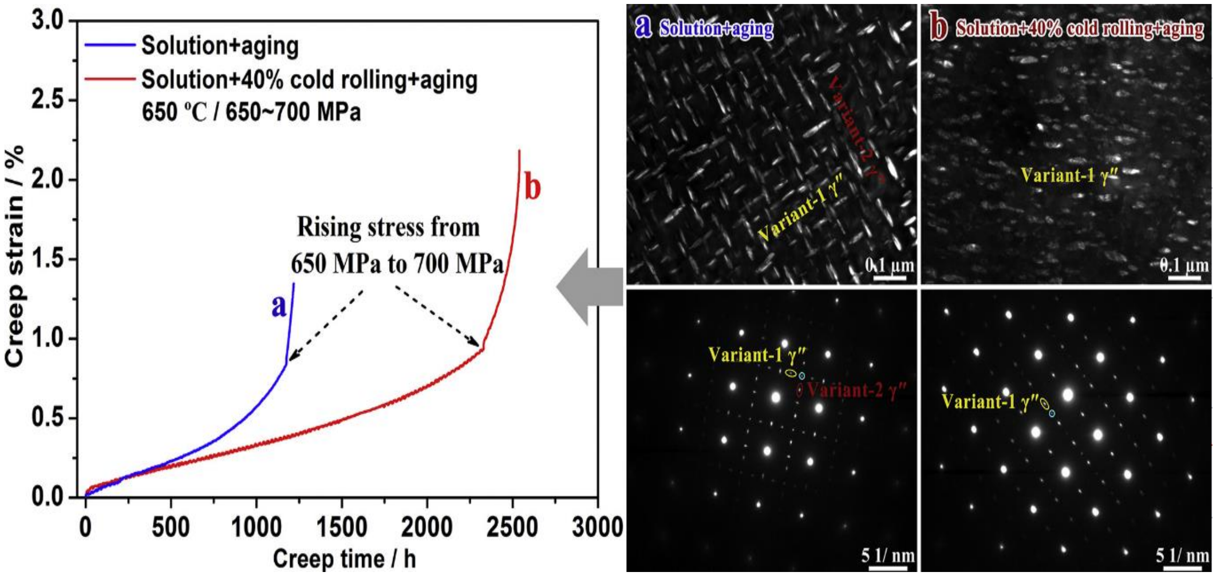

Figure 6.
Shows the creep strain in presence of stress.

- **René 88**: This is a higher-performance nickel-based superalloy designed for high-temperature applications. It features a fine microstructure with additions of rhenium, which enhances creep resistance and thermal stability.

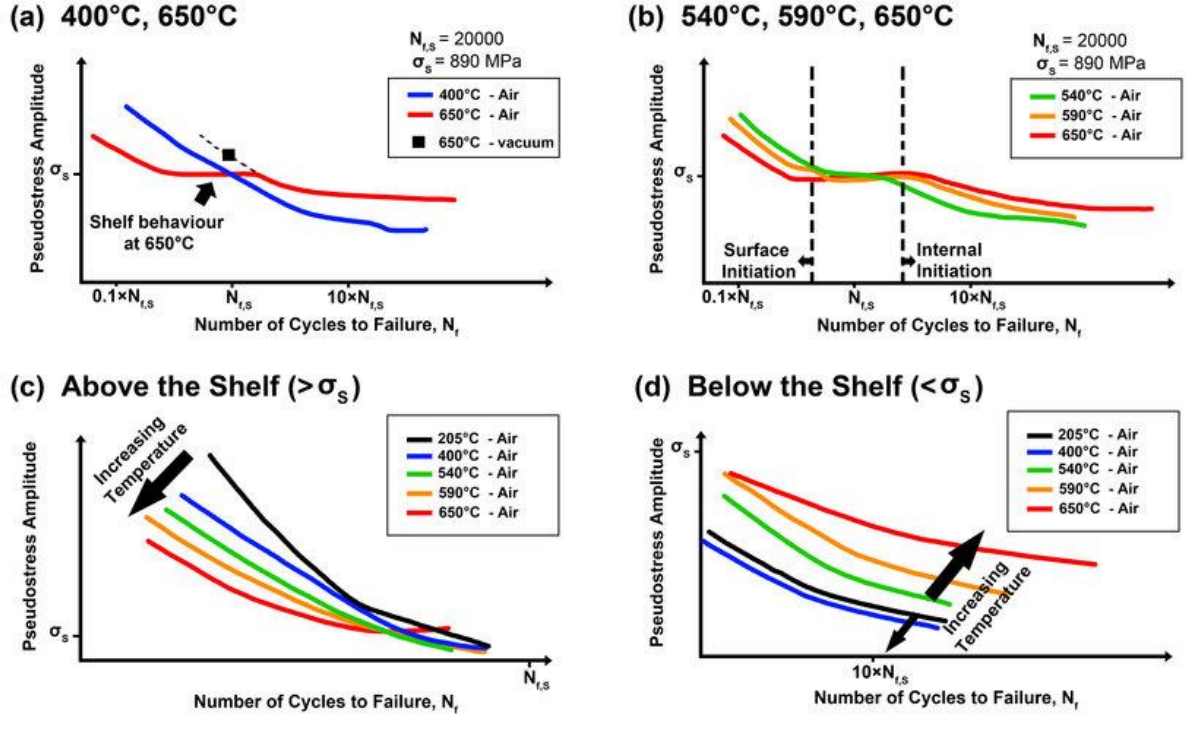

Figure 7.
S-N data for René 88DT at 205C, 400C 540C, 590C and 650C for specimens tested in air in strain control.

The curve suits were extracted from extra than 2 hundred checks at every temperature. The y-axis is given as pseudo stress amplitude. The S-N curves for temperatures better than 540 degrees show a plateau at pseudo stress amplitude of about 890 MPa indicating a competing failure mode.

3.2. Experimental Conditions

- **Temperature Ranges**: Tests are conducted inside a extend of 600–1200°C. This extend is chosen to assess the alloys' execution beneath conditions recreating operational situations, such as those found in aviation and control era.
- **Stress Conditions**: Tests are regularly performed beneath controlled stretch levels, which may shift depending on the particular application necessities. The push is connected persistently amid the creep tests to reenact real-world stacking conditions.

3.3. Creep Testing Methods

- **Test Methods**: Creep tests at raised temperatures are performed utilizing standardized strategies such as ASTM E139. The tests include subjecting examples to a consistent stack at high temperatures for amplified periods.
  These test strategies cover the assurance of the sum of distortion as a work of time (creep test) and the estimation of the time for break to happen when adequate drive is show (crack test) for materials when beneath consistent malleable powers at steady temperature. It too incorporates the fundamental necessities for testing equipment. For data of help in deciding the alluring number and length of tests, reference ought to be made to the item determination.
- **Test Duration**: Creep testing is conducted for varying durations, often ranging from a few hours to several hundred hours, depending on the desired data points and the specific material behavior being studied.
- **Measurement Techniques for Strain**:
  - **Extensometers**: Creep testing is conducted for changing lengths, frequently extending from many hours to a few hundred hours, depending on the specified information focuses and the particular fabric behavior being considered.
  - **Digital Image Correlation (DIC)**: High-precision extensometers are utilized to degree the stretching of the example amid testing. These can be mechanical or optical, giving exact strain estimations Figure 8.

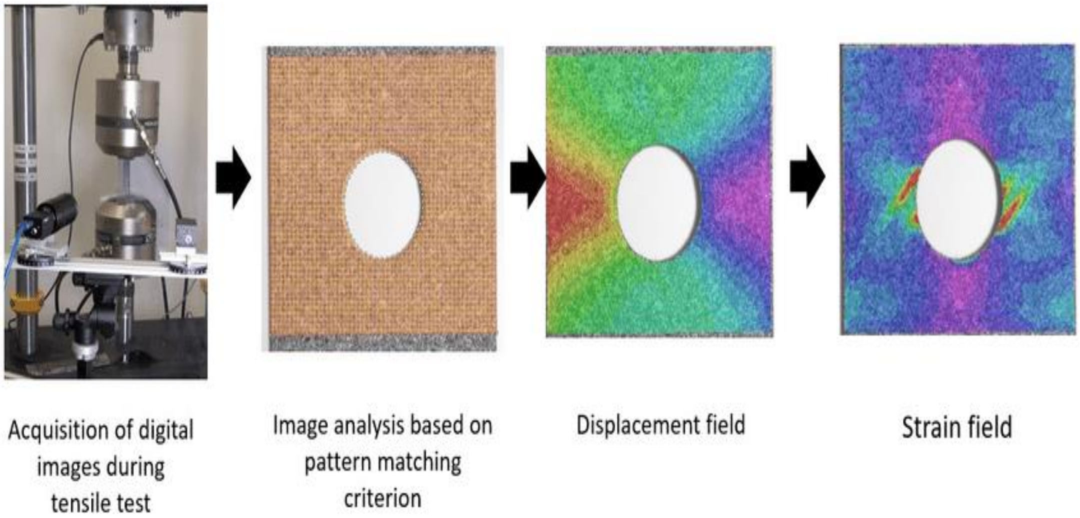

Figure 8.
Scheme of digital image correlation (DIC) procedure.

This experimental setup aims to assess the mechanical properties and durability of nickel-based alloys under high-temperature and high-stress conditions, providing valuable insights into their performance for industrial applications.

4. Simulation and Results

This chapter shows MATLAB code for analyzing the effect of temperature on creep resistance in nickel-based alloys. The code assumes the following data for stress, strain, and time under different temperature conditions.

```
strain_Inconel718 = [0, 0.01, 0.02, 0.04, 0.07, 0.1, 0.13, 0.16, 0.19, 0.21, 0.23]; % creep strain data
strain_Rene88 = [0, 0.005, 0.01, 0.025, 0.045, 0.07, 0.09, 0.11, 0.13, 0.15, 0.17]; % creep strain data
temperature = [600, 800, 1000, 1200]; % Temperature in °C
% Temperature-based creep data
strain_temp_600C = strain_Inconel718 .* (600 / 1200);
strain_temp_800C = strain_Inconel718 .* (800 / 1200);
strain_temp_1000C = strain_Inconel718 .* (1000 / 1200);
strain_temp_1200C = strain_Inconel718 .* (1200 / 1200);
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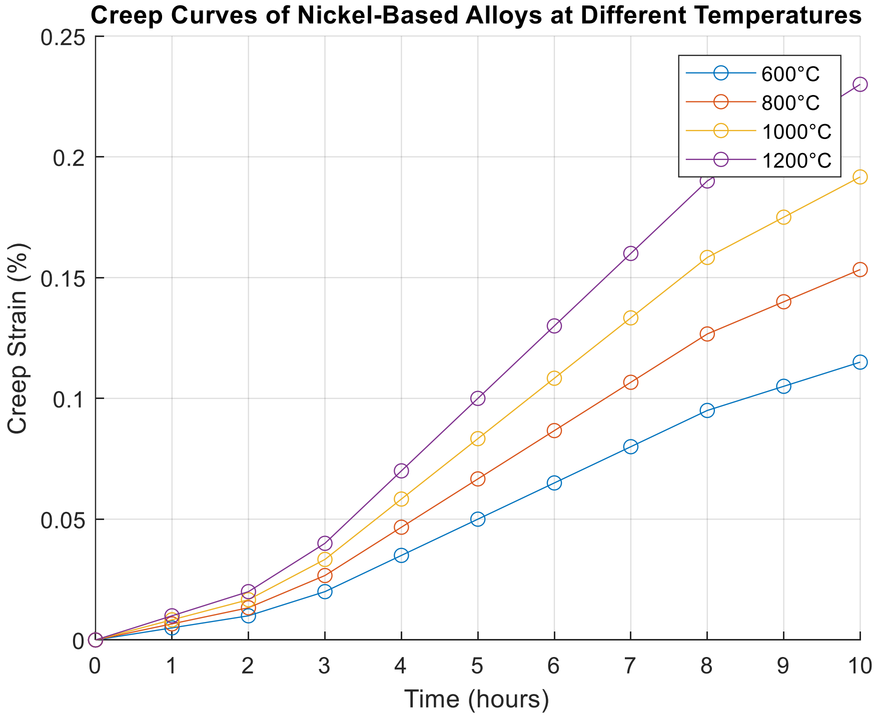

Figure 9.
Creep curves of Nickel based alloys at different temperatures.

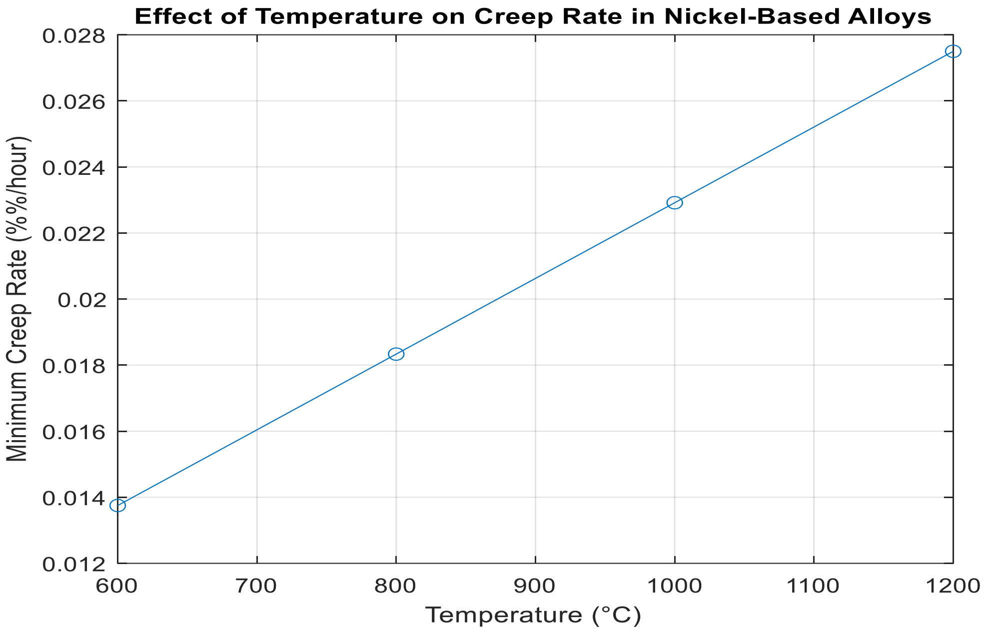

Figure 10.
Effect of temperatures on creep minimum rate in Nickel based alloys.

1. **Data Input**: Time and strain data are provided for different temperatures (600°C, 800°C, 1000°C, 1200°C). You should replace this example data with actual experimental results.
2. **Creep Curves**: Plots the creep strain vs. time for different temperatures.
3. **Creep Rate Calculation**: Estimates the secondary creep rate by calculating the slope of strain over time in a selected region (secondary creep region).
4. **Effect of Temperature on Creep Rate**: Finally, the code plots how the creep rate changes with increasing temperature.

4.1. Output

- Creep curves showing the progression of strain over time for different temperatures.
- Creep rate values at different temperatures.
- A plot displaying the relationship between temperature and creep rate.

This will give a clear visual representation of how temperature affects the creep resistance of nickel-based alloys used in gas turbines.

- This code models how creep rate in nickel-based alloys changes with temperature, following an Arrhenius-type behavior. The relationship highlights that as temperature increases, the creep rate accelerates, providing insights for design in high-temperature applications such as gas turbines. You can modify constants like stress, activation energy (Q), and the pre-exponential factor (A) to match specific alloy properties Figure 11.

DOI: 10.55214/25768484.v8i6.2222

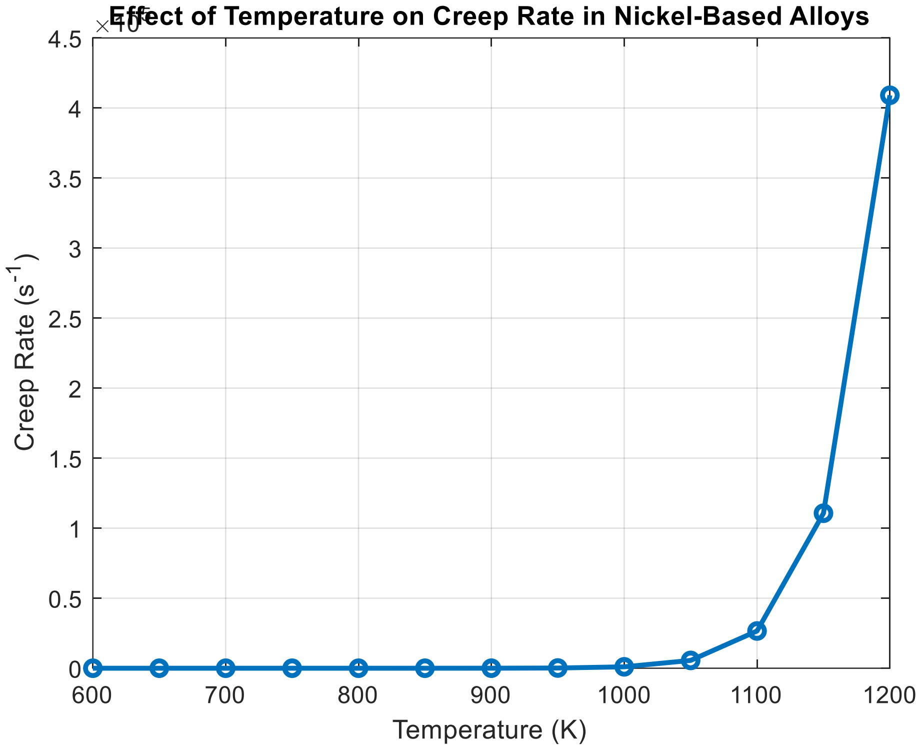

Figure 11.
Effect of temperatures on creep rate in Nickel based alloys.

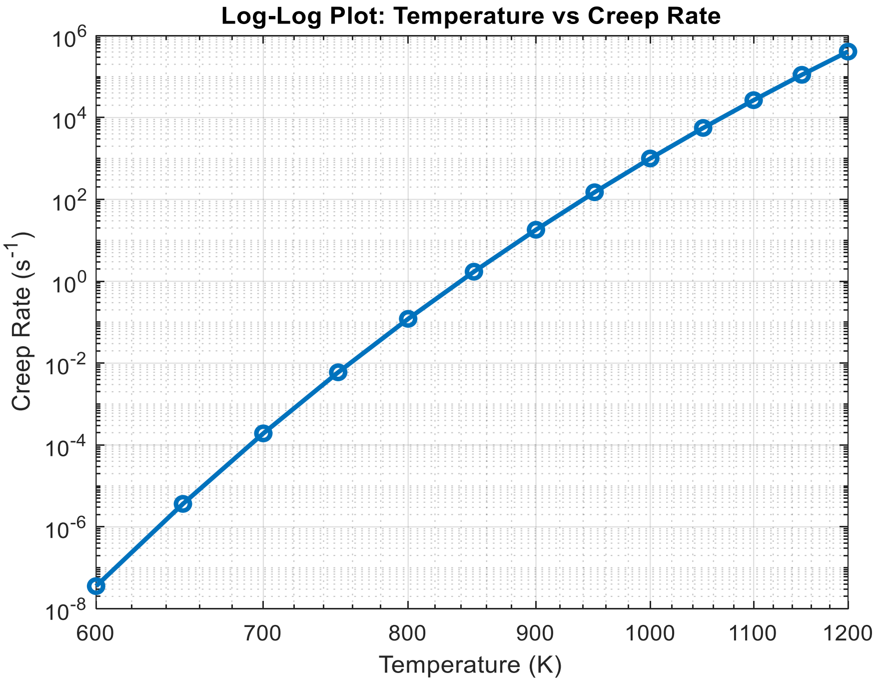

Figure 12.
Logarithmic plot of Effect of temperatures on creep rate in Nickel based alloys.

5. Conclusion

Nickel-primarily based totally alloys show off various creep resistance at special temperatures. Higher temperatures commonly result in decreased creep resistance because of elevated diffusion and dislocation mobility. At increased temperatures, mechanisms like dislocation creep and diffusion creep emerge as prominent, affecting the cloth`s average overall performance over time. The composition of nickel-primarily based totally alloys extensively impacts their creep conduct. Elements like chromium, aluminum, and titanium beautify creep resistance with the aid of using forming strong oxide layers and strengthening precipitates.

Understanding temperature outcomes allows in optimizing turbine operation and protection schedules. It informs cloth choice for additives subjected to high-temperature environments to make certain long-time period reliability and overall performance.

5.1. Future Research Directions

Further studies should recognition on superior alloy layout and simulation strategies to expect long-time period creep conduct accurately. Additionally, exploring novel warmth remedy strategies should beautify creep resistance with out compromising different mechanical properties. Overall, this evaluation underscores the essential position of temperature in figuring out the creep resistance of nickel-primarily based totally alloys, important for enhancing the performance and sturdiness of fueloline turbine additives.

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DOI: 10.55214/25768484.v8i6.2222