Influence of Plastic Deformation on Creep Behaviour of NiMoCr Alloy

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(Received April 30, 2003)

ABSTRACT

Creep behaviour of nickel-base solid solution strengthened NiMoCr alloy after different applied hot and cold rolling conditions was investigated. The results of creep tests showed that the creep characteristics including strain rate, fracture strain, and lifetime were greatly dependent on the plastic deformation conditions carried out prior to the creep. Failure process including crack nucleation and crack propagation was strongly dependent on grain size. Fine recrystallized structures have provided much less resistance to creep deformation compared to coarse grain size. A comprehensive study of creep deformation as a function of plastic deformation conditions of NiMoCr alloy is also presented.

Key words: solid solution strengthened alloy, hot rolling, cold rolling, recrystallization, creep, failure

1. INTRODUCTION

It is well recognized that mechanical properties such as tensile, creep, and low cycle fatigue (LCF) are strongly dependent on morphology of grain structure, which can be obtained from plastic deformation conditions /1,2/. The effects of temperature during hot rolling, deformation introduced during hot and cold rolling, as well as annealing conditions, are related to the microstructure development in order to satisfy the creep capabilities of the alloy. The high temperature creep strength resistance is considered to be the mechanical property, which is of major concern in this alloy. Ordinary uniform coarse grain size is favouring creep strength and crack growth resistance, and ductility for next step forming. Optimization and control of uniform grain size and morphology can be achieved by recrystallization process either after hot and/or cold rolling.

In this study, creep behaviour of modified microstructure in NiMoCr alloy, which has very similar chemical composition to Hastelloy N, after different plastic deformation conditions and various annealing times, was investigated.

2. EXPERIMENTAL PROCEDURE

The investigated material was solid solution strengthened nickel base NiMoCr alloy, similar to Hastelloy N, with chemical composition given in Table 1 by mass %. The experimental alloy was produced by casting process and forming process with multi-step forging and reheating. The evaluating alloy formability and mechanical properties were investigated in previous

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Table 1
Chemical composition of NiMoCr alloy (mass %)

Ni [%]	[redacted]	Cr [%]	Fe [%]	[redacted]
73	17	6	2.8	1.2

works /3-9/. Selected controlled rolling processes were employed for simulation in order to find the optimal operation conditions. The details of hot rolling and annealing simulations followed by cold rolling process are shown in Table 2. To assess the effect of additional cold deformation on structure development following programme B, the specimens were subjected after cooling to cold rolling and later annealed at 1403 K for 1.5 ks. Subsequently, all the specimens were machined for creep testing. The creep tests were performed in air, using creep-testing machines. The creep tests were carried out at stress level of R = 160 MPa and temperature of 983 K. The specimen elongation, as time function, was recorded by two extensometers. The testing temperature was controlled by two Pt-PtRh thermocouples by means of thermal compensator. The temperature was maintained within the range of ± 5 K.

3. RESULTS AND DISCUSSION

3.1 Creep behaviour

The creep results for deformation conditions corresponding to programme A are presented in Fig.1. All dependences showed that the change in annealing time did not provide great effect on creep lifetime (≈ 120 ks). The only quenched or air cooled specimens after hot rolling had provided a much longer lifetime and correspondingly a lower creep rate than in the case of all annealed specimens. This was probably due to the prevailing effect of the stored work hardening still remaining in the structure. The significant role in creep resistance of these specimens could be due to non-uniform grain size-structure as well. The structure consisted of primary cast grains resulted not yet completely broken down and partially replaced by finer recrystallized grains in small fracture portions. Creep lifetime for only air-cooled specimens was slightly lower than for quenched specimens. The stored work for air-cooled specimens was probably lower than that from quenched specimens. Regardless that these cooled specimens (A1, A2) had very high creep strength, they will not be considered for further use because of their low corrosion resistance due to the increase in the internal energy. This leads to a general decrease in corrosion resistance and may introduce the possibility of stress-corrosion cracking at proposed working conditions /10/. For further industrial alloy application

Table 2
Hot rolling, cold rolling and annealing conditions

Specimen No.	Heating Temperature before HR	[redacted]	[redacted]	Cold Rolling Deformation [%]after Air Cooling	Annealing at 1403 K for 1.5 ks
A	1473 K/1.8 ks	18% + 18%	Quenching air cooling t_{anneal} = 0.18-3 ks	-	-
B	1373 K/1.8 ks	11.3% + 13.6%	Quenching t_{anneal} = 0.18-3 ks	0-6.0 %	No/Yes
C	1473 K/1.8 ks	18% + 18%	-	4.8-20 %	Yes

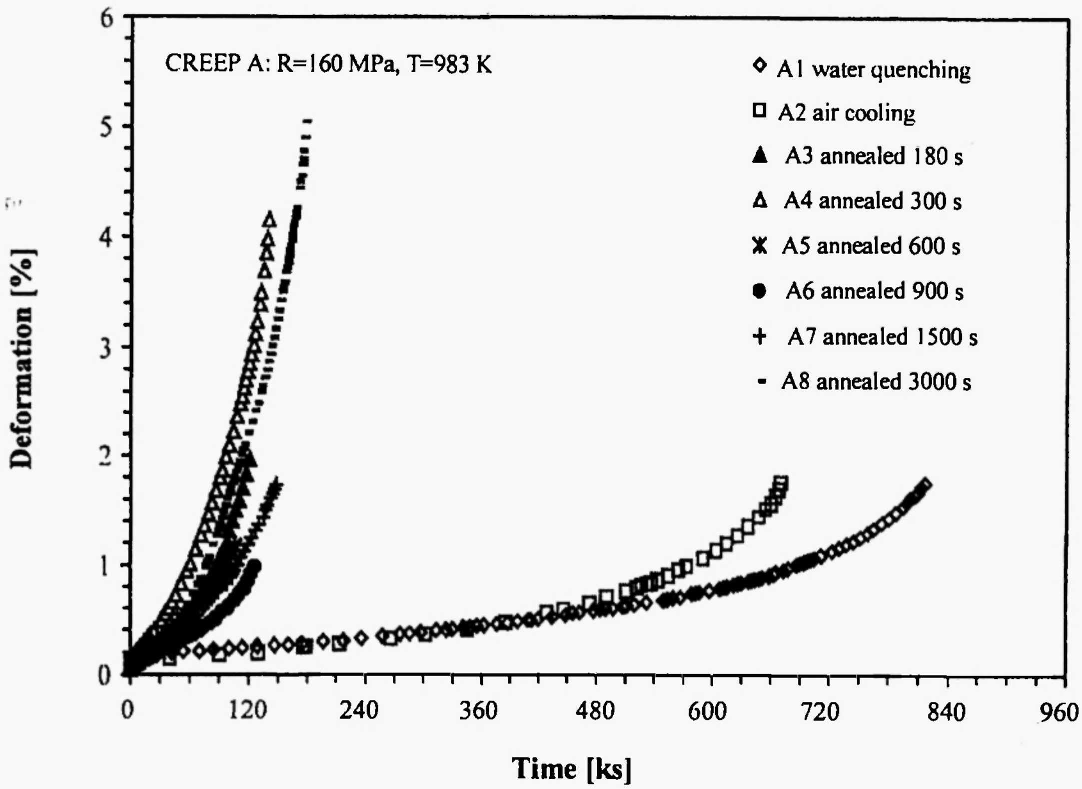

Fig.1. Creep behaviour for programme A.

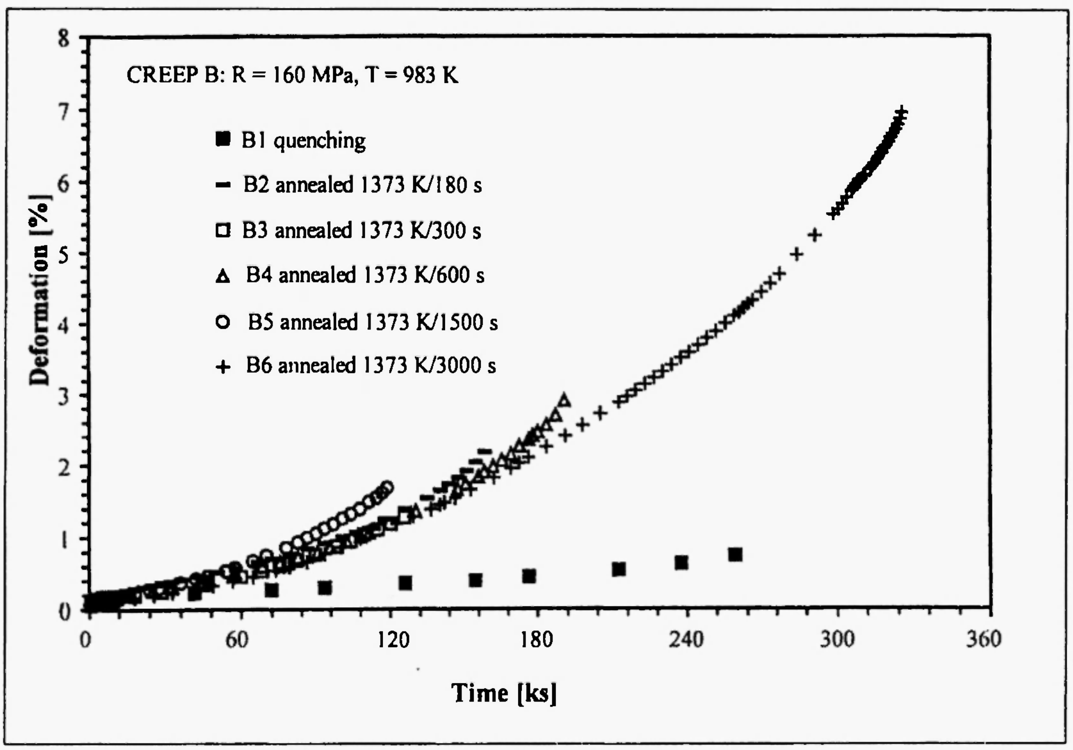

Fig.2. Creep behaviour for programme B.

only annealed or recrystallized microstructures will be further investigated and developed in order to find the most proper processing condition to satisfy forming ability and creep strength of alloy. The creep behaviour of the alloy processed according to programme B, as results showed in Fig. 2, has quite a similar course to programme A. From obtained dependencies, it is possible to relate the relationship between creep lifetimes and applied annealing times. It can be concluded when processing water quenched specimens that the creep strength according to programme A was better than those processed according to programme B. The higher effect of introduced hot working is supposed to produce higher driving effect for recrystallization into specimens, processed according to programme A. The higher stored deformation energy would have an effect by increasing creep strength in deformation behaviour of specimens. However, regardless of the processing conditions in both programmes of the alloy, the creep lifetime decreased very significantly if any annealing followed the hot deformation. This means that, when a deformed structure was replaced by recrystallization, the creep life would decrease. The effect of work hardening in a deformed structure was eliminated quickly by the recrystallization process, no matter that different hot plastic deformations were used in programmes A and B. A small increase for both programmes in creep endurance for longer time of annealing over 1.5 ks was observed. This could have been related to grain size increasing when recrystallization process was more advaced. It is also in agreement with kinetics process, as is shown in Fig.3.

The effect of cold deformation introduced into the thermomechanical process (programme C) is presented in Fig. 4. These results showed that the effect of additional cold rolling introduction on level 6% produced better creep results for specimen B7 than for C2, where more hot deformation was applied. It seems that the decrease of plastic deformation during hot rolling seen in the B7 specimen caused more growing grains than that resulting in sample C2. The following coarser structure probably caused higher creep lifetime as the effect of grain size on creep behaviour. Considering the creep results for programmes B and C, there the introduction of cold deformation had a positive effect on creep life. This was probably due to the dominant effect of a larger amount of finer recrystallized grain structure in programme C, which resulted from annealing after the introduction of higher hot deformation. The coarsening microstructure resulting in programme B may also be considered when evaluating factors which support creep strength

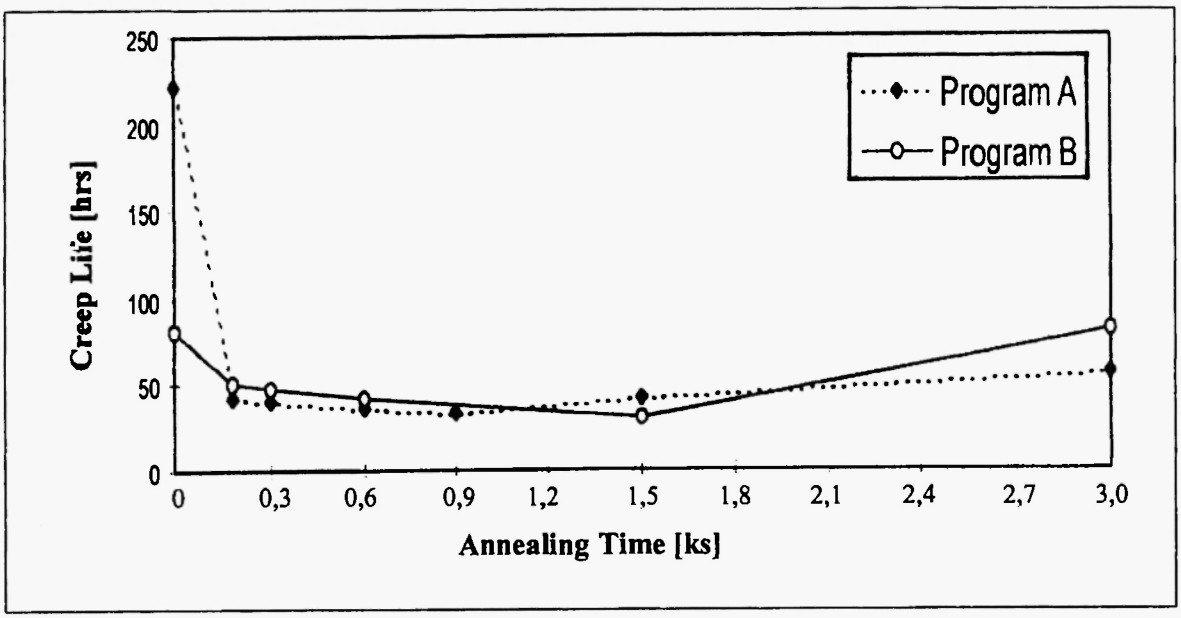

Fig.3. The relationship between creep life and annealing time considering programmes A and B.

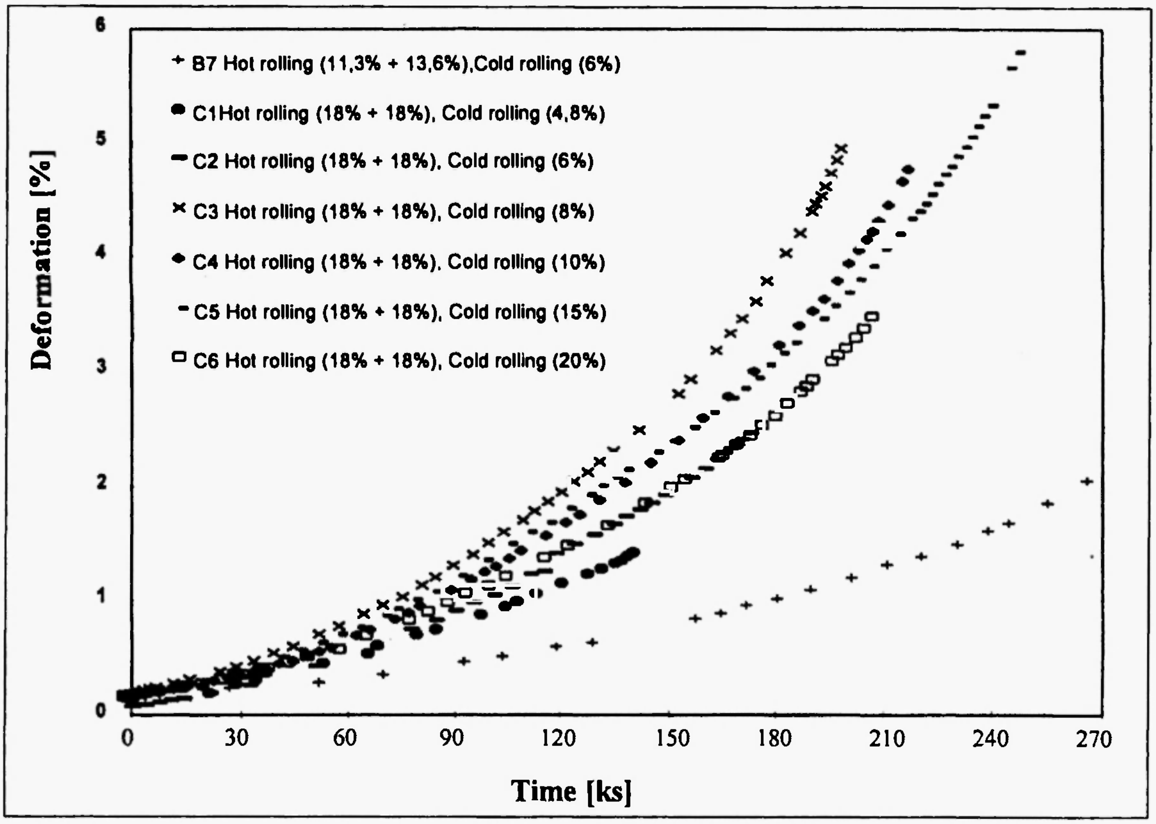

Fig.4. Creep behaviour for programme C.

resistance improvement. Only hot and cold deformation conditions in programme C are able to modify the alloy structures. The more uniform microstructure from programme C is also expected to provide better formability, which is required for further advanced shaping of alloy sheet rolling.

3.2 Microstructure and fracture relationship

The crack nucleation and crack propagation in the creep deformation process was related to creep mechanism. The metallography analysis of ruptured specimens provided the proof on major damage mechanism. The grain boundaries were the initiation site for crack nucleation and crack propagation. At the initial stage of damage the critical crack usually opened at free specimen surface by intergranular cleavage, shown in Fig. 5. The crack from there, as damage process continued, propagated along grain boundaries and the majority of failure processes continued by intergranular cleavage. The morphology of fracture surface is documented in Fig. 6. The corresponding fracture mechanism resulted in very low total creep

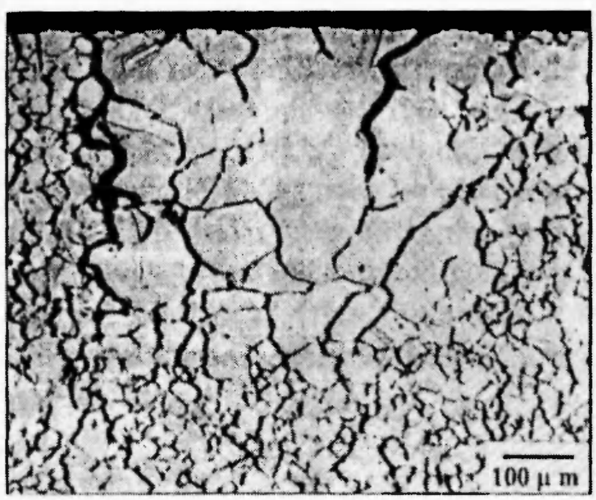

Fig.5. Surface crack initiation and cracks network

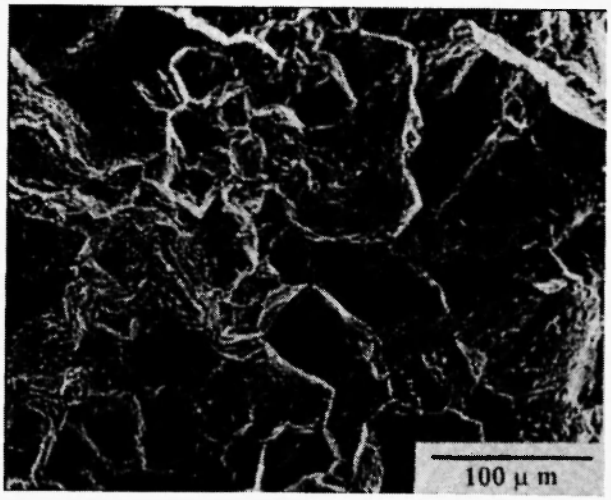

Fig.6. SEM micrograph of fracture surface

deformation. Only an increase in strain was observed in the case of the longest time of applied annealing. The additional cold work showed a beneficial influence on creep deformation behaviour of alloy, resulting in life extension at the corresponding lower strain rate.

4. CONCLUSIONS

Based on the literature data, and on our own experimental results, it is possible to draw the following conclusions:

1. The recrystallization process introduced after plastic deformations resulted in creep life reduction regardless of the annealing period and specimen reduction. Annealing time prolongation over 1.5 ks appeared to be a critical time in respect of creep life. Prolonging the period of annealing over this limit, the creep life increased in small contribution.
2. The larger deformation during the second hot rolling steps in programme A provides more uniform and finer recrystallized grain structures than those in programme B. However the finer grain size resulted in slightly lower creep strain rate and lifetime.
3. The experimental regimes where the longest annealing time of 3 ks for all thermomechanical procedures did not guarantee the structure development in order to receive the uniform grain structure; in any case, the prolonged annealing time produced a coarser grain structure with slightly better creep lifetime.
4. The creep strength of cold worked specimens treated according to B7 regime was better than that of specimens treated according to C1 – C6 regimes.
5. The dominant creep fracture mechanism, regardless of the experimental regime used, was intergranular either for crack nucleation or crack propagation.

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