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# The Varying Effects of Uniaxial Compressive Stress on the Bainitic Transformation under Different Austenitization Temperatures

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**Abstract:** In this study, thermal simulation experiments under different austenitization temperatures and different stress states were conducted. High-temperature laser scanning confocal microscopy (LSCM), thermal dilatometry, and scanning electron microscope (SEM) were used to quantitatively investigate the effects of the uniaxial compressive stress on bainitic transformation at 330 °C following different austenitization temperatures. The transformation plasticity was also analyzed. It was found that the promotion degree of stress on bainitic transformation increases with the austenitization temperature due to larger prior austenite grain size as well as stronger promoting effect of mechanical driving force on selected variant growth at higher austenitization temperatures. The grain size and the yield strength of prior austenite are other important factors which influence the promotion degree of stress on bainitic transformation, besides the mechanical driving force provided by the stress. Moreover, the transformation plasticity increases with the austenitization temperature.

**Keywords:** bainitic transformation; stress; transformation plasticity; austenitization temperature

## 1. Introduction

In order to optimize the microstructure and the properties of steels, a comprehensive and deep understanding of the solid-to-solid phase transformation is essential. Residual stresses are always generated during the processes of welding, forging, and hot rolling; as a consequence, the subsequent phase transformation process is then inevitably affected by these stresses [1]. Therefore, extensive researches on the interactions between the stress and the solid-to-solid phase transformations are necessary for the optimization of various properties of steels.

In recent years, the effect of a stress on the isothermal bainitic transformation, a well concerned solid-to-solid phase transformation, has been a hot topic. It was established that bainitic transformation is accelerated by a uniaxially applied stress, whether the magnitude of the stress is above the yield strength of the parent austenite or not [1–8]. It should be noted that, when the stress exceeds the yield strength of austenite, the prior austenite will be deformed. It was reported that large pre-deformation of austenite hinders the bainitic transformation without stress and causes the mechanical stabilization of austenite [7,9,10]. The present study focuses on the stress below the yield strength of prior austenite. A well-accepted reason for the acceleration by stress is that the uniaxial stress provides additional mechanical driving force to the total driving force needed for a bainitic transformation [2–5,11]. By this process, the stress favors the growth of certain crystallographic variants of bainite, which best complies

with the stress. The mechanical driving force is proportional to the magnitude of the applied stress, so the degree of this acceleration should increase with the stress. This has been observed in some experiments [1,4,5]. It seems that the promotion degree of the stress on bainitic transformation is directly determined by the magnitude of the mechanical driving force. However, this is not an actual fact, as Shipway and Bhadeshia [3] found that the acceleration effect by the same stress is more obvious at a higher transformation temperature, although the same mechanical driving force is provided. This occurs because the chemical driving force is lower, and the mechanical driving force provided by the stress accounts for a larger proportion at a higher transformation temperature. Similar results were obtained by Hase *et al.* [4]. Therefore, a review of the existing studies suggests that the proportion of the mechanical driving force may be a decisive factor in the promotion degree of stress on the bainitic transformation.

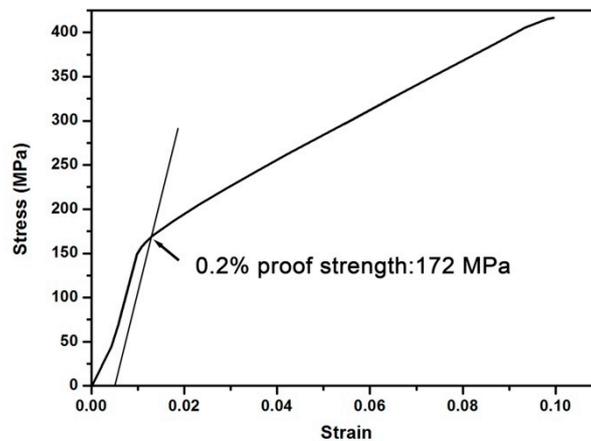
Austenitization temperature is another important technical parameter for the bainitic transformation besides the transformation temperature. Therefore, it is interesting to investigate whether the promotion degree of a uniaxial stress on bainitic transformation is the same at different austenitization temperatures. In purview of the current researches, it can be apparently assumed that, if the transformation temperature and stress are kept constant, the promotion degree will be the same at different austenitization temperatures due to the same proportion of the mechanical driving force. However, the result obtained in the present study is actually opposite. Therefore, one of the main purposes of this study was to analyze the relationship between the austenitization temperature and the promotion degree of stress on bainitic transformation. The decisive factors to the promotion degree of stress on bainitic transformation were analyzed.

In addition, another interesting point about the effect of stress on bainitic transformation is that the transformation strains of specimens along the different directions are anisotropic, demonstrating that the anisotropic plastic deformation occurs during the bainitic transformation under a stress, even if its magnitude is below the yield strength of prior austenite [1–3,12,13]. This anisotropic plastic deformation is usually called transformation plasticity (TP) strain [1–3]. Anisotropic volume changes are a generally unfavorable effect. The study of TP strain is important for predicting and minimizing the anisotropic volume changes brought about by phase transformation in steels [5]. It was found that the TP strain increases with the stress and is influenced by the transformation temperature [2,3,5]. Lambers *et al.* [14,15] investigated the effects of pre-deformation, stress, and austenite grain size on the TP strain during martensite transformation and bainitic transformation. It was found that pre-deformation of supercooled austenite at a lower temperature (340 °C) caused pronounced TP strain, but no TP strain was brought by pre-deformation of stable austenite at higher temperatures (880 °C and 1050 °C). However, the relationship between the austenitization temperature and TP strain caused by elastic stress was not analyzed in detail in their studies. Therefore, another purpose of this study is to analyze the effect of austenitization temperature on the TP strain caused by elastic stress.

## 2. Materials and Methods

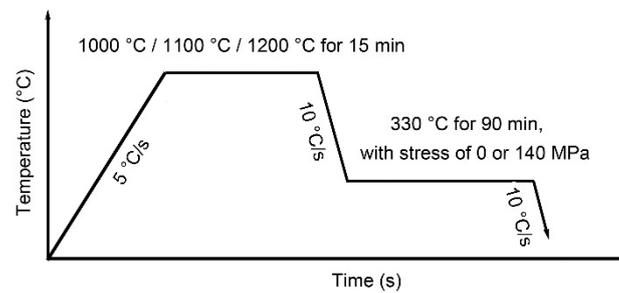
The experimental material used was a Fe–C–Mn–Si alloy with a composition of Fe-0.45C-2.0Si-2.8Mn (wt %). The steel was refined and cast in the form of a 50-kg ingot using a laboratory-scale vacuum furnace. The material was then hot-rolled and air-cooled to room temperature followed by a tempering at 700 °C for 24 h in order to facilitate machining. In order to select proper stress, a compression test was conducted to determine the yield strength of supercooled austenite at 330 °C on the Gleeble 3800 simulator. The specimen was heated to austenitization temperature of 1200 °C at 5 °C/s and held for 900 s followed by cooling to 330 °C at 10 °C/s. Once the temperature reached 330 °C, 20% compressive deformation was applied on sample at 0.02 s<sup>-1</sup>. Then, the specimens were cooled to the ambient temperature at 10 °C/s. The stress–strain diagram of the supercooled austenite (austenitized at 1200 °C) at 330 °C is shown in Figure 1. The 0.2% proof strength of the supercooled austenite at 330 °C is calculated to be 172 MPa. The austenite grains in the specimens austenitized at 1100 °C and 1000 °C are smaller than that austenitized at 1200 °C (Figure 4). According to the Hall–Petch Effect, the

yield strength of austenite in the specimens austenitized at 1100 °C and 1000 °C should be larger than 172 MPa. Therefore, the stress (140 MPa) used in the present study is smaller than the yield strength of supercooled austenite at 330 °C for all specimens.



**Figure 1.** The stress–strain diagram of the supercooled austenite (austenitized at 1200 °C) at 330 °C.

The thermal simulation experiments were conducted on a Gleeble 3800 simulator. Cylindrical specimens, 10 mm in diameter and 15 mm in length, were used. As shown in Figure 2, the specimens were heated to austenitization temperatures of 1000 °C, 1100 °C, and 1200 °C at 5 °C/s, respectively, and held for 900 s followed by cooling to 330 °C at 10 °C/s for isothermal bainitic transformation for 5400 s. Then, the specimens were cooled to ambient temperature at 10 °C/s. Different uniaxial compressive stresses (0, 140 MPa) below the yield strength of the austenite were rapidly applied to the specimens during the isothermal holding at 330 °C. The dilatations along the radial and axial directions were measured in all specimens during the whole experimental process. It should be noted that, in the experiments at 0 MPa stress, a very small stress (less than 3 MPa) was loaded to fix the specimens, and this small stress was so small that it has a very small effect on the bainitic transformation during isothermal holding at 330 °C. The numbers of different specimens corresponding to different thermal parameters are shown in Table 1. The simulated specimens were cut along the axial direction. The surfaces of the axial section of the specimens were polished and etched by 4% nital. Then, the microstructure of the axial section of simulated specimens was examined by a Nova 400 Nano scanning electron microscope (SEM). The high-temperature laser scanning confocal microscopy (LSCM) was used for *in situ* observation of the prior austenite grains in the specimens austenitized at different temperatures. Samples for LSCM were selected from original material and machined to a cylinder 6 mm in diameter and 4 mm in height. The top and bottom surfaces of samples were polished conventionally to keep the measurement face level and minimize the effect of surface roughness. The investigations were conducted on a VL2000DXSVF17SP laser scanning confocal microscope. The specimen chamber was initially evacuated to  $6 \times 10^{-3}$  Pa before heating and argon was used to protect specimens from surface oxidation [16,17]. The experimental routes for LSCM were the same as those for thermal simulation experiments without stress (Figure 2). Five photographs were taken per second during the LSCM experiments. The principle for *in situ* observations of austenite grains is that the delineation of grain boundaries at high temperatures under vacuum occurs due to thermal etching. In addition, micro-hardness of the specimens was measured on an HV-1000A metallographic micro-hardness tester in order to identify different phases in the microstructure.



**Figure 2.** An illustration of the experimental procedure.

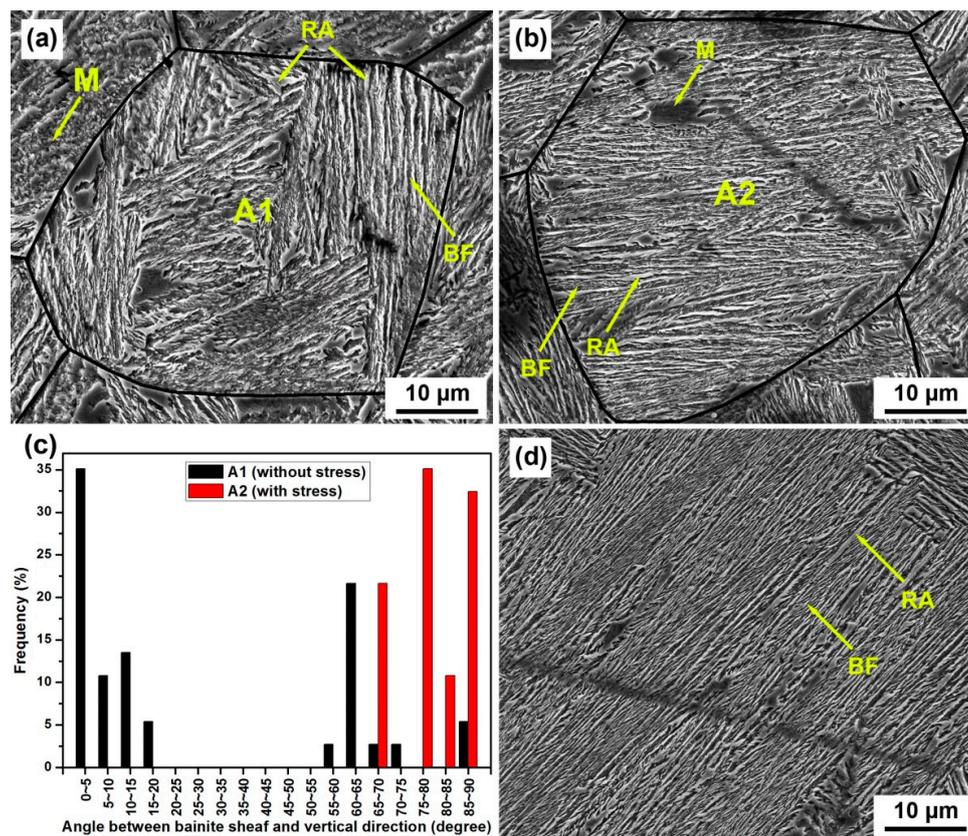
**Table 1.** The numbers of experimental specimens corresponding to different thermal simulation parameters.

Number	Austenitization Temperature (°C)	Isothermal Temperature (°C)	Stress (MPa)
1000-nos	1000	330	0
1000-stress	1000	330	140
1100-nos	1100	330	0
1100-stress	1100	330	140
1200-nos	1200	330	0
1200-stress	1200	330	140

### 3. Results

#### 3.1. Micrographs

Figure 3a,b show a typical comparison of the microstructure between the specimens with and without stress (1000-stress and 1000-nos). Grain boundaries (GBs) are marked by black lines. The microstructure of different specimens shows the presence of lath-like bainitic ferrite (BF), retained austenite (RA), and martensite (M). RA shows film-like and blocky morphologies and film-like RA distributes between BF. Bainite and martensite were identified according to the micro-hardness. For example, the micro-hardness for bainite and martensite in the specimen 1000-nos were measured to be about 491 HV and 586 HV, respectively. The authors' previous study [18] and other similar microstructures [4,19] showed that the microstructure of the studied steel consists of BF, M, and RA, and RA distributes between bainite plates. Two representative prior austenite grains A1 and A2 are selected in the specimen with stress and that without stress, respectively, and the comparison of bainite morphology in the two austenite grains is representative. A quantitative statistics of the bainite orientations in austenite grains A1 and A2 are given in Figure 3c by measuring the angle between every bainite sheaf and the vertical direction by the software Image-Pro Plus. It shows that the angle distribution in austenite A2 is less random, indicating that the orientation of bainite sheaves become more uniform under the effect of stress. In addition, Figure 3d shows the bainite morphology in the specimen 1200-stress. A comparison between Figure 3b,d indicates that, when the austenitization temperature is higher, the stress makes the orientation of bainite sheaves much more uniform. Moreover, the lengths of bainite sheaves in austenite grains A1 and A2 are measured and normalized by dividing corresponding grain diameter in order to eliminate the effect of austenite grain size on the length of bainite sheaves. The normalized average lengths of bainite sheaves in austenite A1 and A2 are 0.37 and 0.44  $\mu\text{m}/\mu\text{m}$ , respectively, demonstrating that the length of bainite sheaves is longer in the specimens with stress.



**Figure 3.** (a) Scanning electron microscope (SEM) micrograph of the specimen 1000-nos (1000 °C, without stress); (b) SEM micrograph of the specimen 1000-stress (1000 °C, with stress); (c) Angle between bainite sheaf and vertical direction in austenite grains A1 and A2; (d) SEM micrograph of the specimen 1200-stress (1200 °C, with stress).

Based on multiple micrographs, the volume fractions of BF were determined by the software Image-Pro Plus. The shape and grayscale of bainite is different from those of the RA and M in SEM micrographs. According to this characteristic, the BF could be tinted with an apparent color by this software. Then, the volume fraction of BF could be determined by calculating the area percentage of the tinted BF in the micrographs. The result (Table 2) indicates that the amount of bainite increases with stress and austenitization temperature. In addition, the difference of bainite amount between the specimen with stress and that without stress increases with the austenitization temperature, indicating that the promotion degree of stress is larger at higher austenitization temperatures.

**Table 2.** Volume fraction of bainite in different samples.

Number	Austenitization Temperature (°C)	Stress (MPa)	Volume Fraction (%)
1000-nos	1000	0	51.2
1000-stress	1000	140	64.7
1100-nos	1100	0	55.0
1100-stress	1100	140	73.5
1200-nos	1200	0	62.2
1200-stress	1200	140	86.1

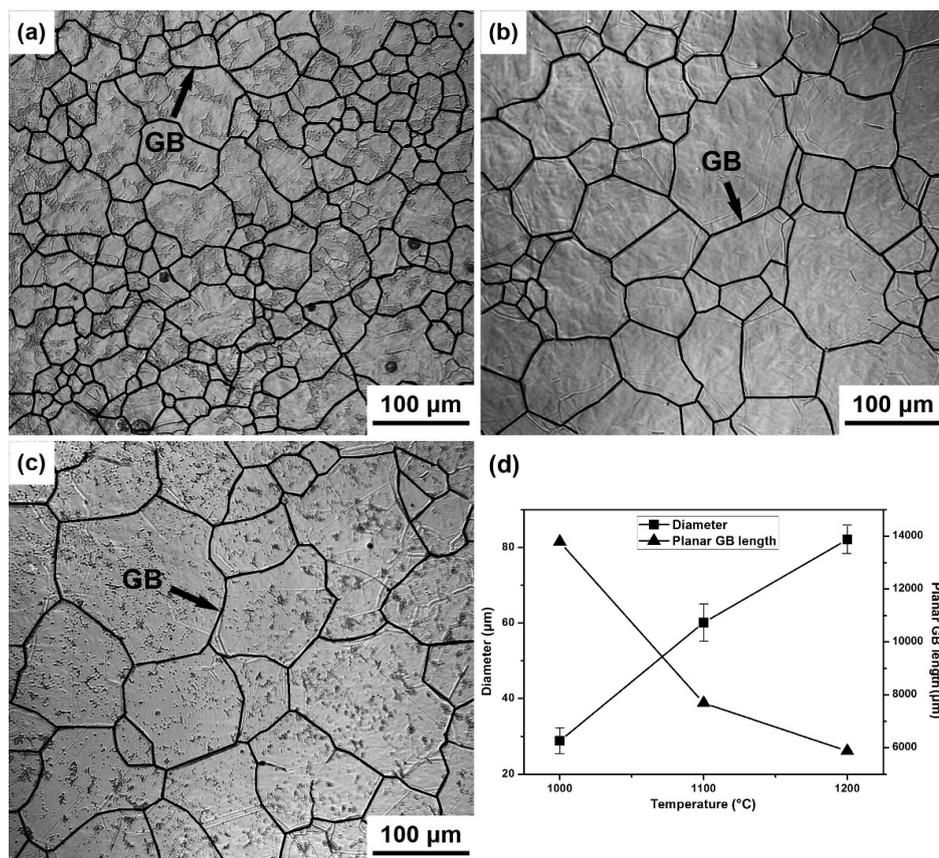
### 3.2. In Situ Observation of Prior Austenite Grains

Figure 4a–c show the *in-situ* observation of prior austenite grains at different austenitization temperatures, in which the GBs is clearly marked by black lines. The prior austenite grain size

is measured by the linear intercept method. The three-dimensional GB area of prior austenite is proportional to the planar GB length, which is accurately measured according to Equation (1) by using the software Image-Pro Plus. Results are shown in Figure 4d.

$$L = S/W \quad (1)$$

where  $L$  is the planar GB length (the length of black lines),  $S$  is the area of marked planar GB lines (the area of black lines), and  $W$  is the width of marked planar GB lines (the width of black lines). Longer planar GB length corresponds to a larger three-dimensional GB area. It shows that the prior austenite grain size increases, and the GB area decreases with the increase in austenitization temperature.



**Figure 4.** *In situ* observation of prior austenite grains at different austenitization temperatures on the LSCM: (a) 1000 °C; (b) 1100 °C; (c) 1200 °C; and (d) prior austenite grain size and planar grain boundary (GB) length.

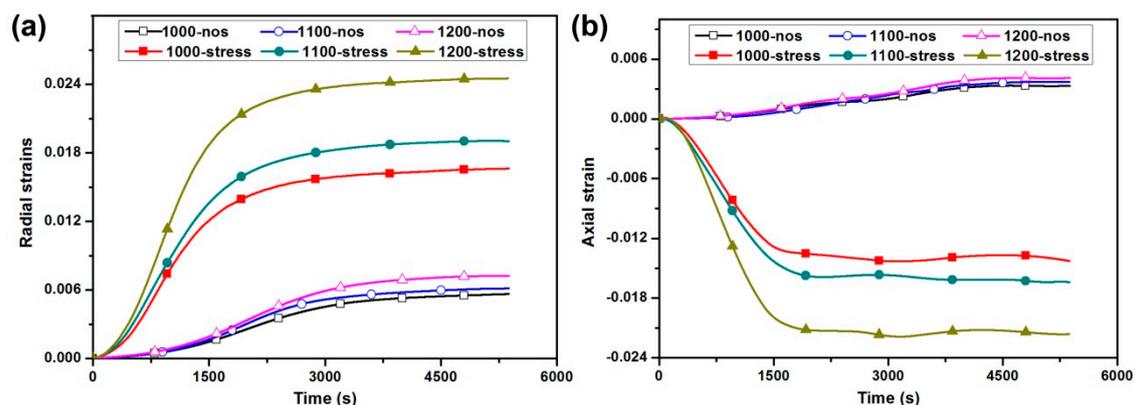
### 3.3. Transformation Strains

Figure 5 gives the dimensional changes of the samples along the radial and axial directions (radial and axial strain), respectively, during the bainitic transformation at 330 °C. The stress applied to the specimens is below the yield strength of prior austenite, so no plastic deformation occurs from this stress. The elastic strain is also eliminated by setting the zero point right after the stress is rapidly imposed. Therefore, the dimensional changes occur solely by the phase transformation from austenite to bainite. As shown in Figure 5, the radial strains increase with the time in all specimens. The axial strains increase with the time in the specimens without stress, while they decrease in those with stress. The contraction in axial direction in the specimens with stress is caused by TP strain. It has been demonstrated theoretically that the value of TP strain could reach 14% if the entire specimen transforms to the most favored variant [2,3]. In addition, austenite is a face-centered cubic (fcc)

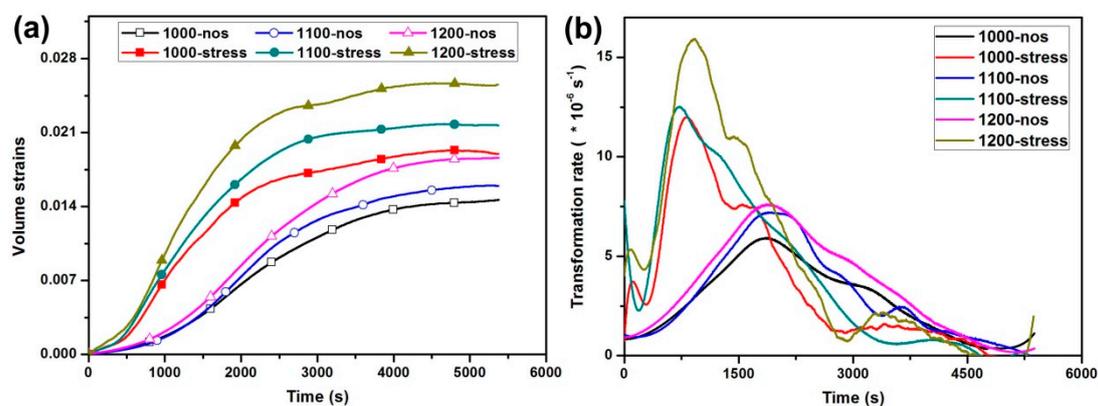
structure and ferrite is a body-centered cubic (bcc) structure. The densities of fcc and bcc are 0.74 and 0.68, respectively [16]. Therefore, an increase in volume occurs during the transformation from  $\gamma$ -austenite to  $\alpha$ -ferrite. Meanwhile, the volume change (volume strain) of the specimen can be used to quantitatively represent the amount of the bainitic transformation during the isothermal holding. The volume strains of different specimens were calculated based on the radial and axial strains (Figure 5) according to Equation (2) [2,3] and are shown in Figure 6a.

$$\Delta V/V = (1 + \varepsilon_L)(1 + \varepsilon_R)^2 - 1 \quad (2)$$

where  $\Delta V$  is the volume change of the specimen,  $V$  is the original volume of the specimen,  $\varepsilon_L$  is the axial strain, and  $\varepsilon_R$  is the radial strain of the specimen.



**Figure 5.** The radial and axial strains of the different specimens during the bainitic transformation at 330 °C: (a) radial strains and (b) axial strains.



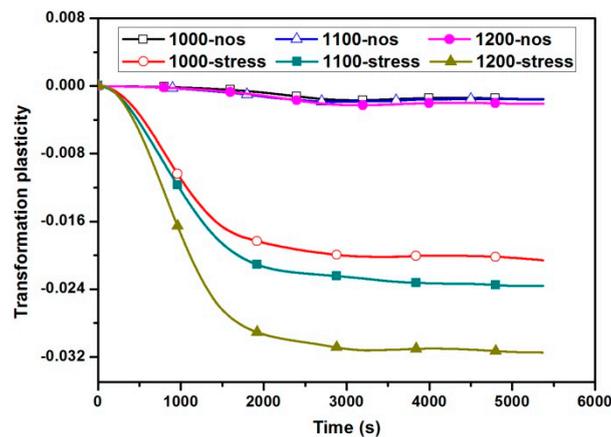
**Figure 6.** The volume strains and bainitic transformation rates of the different specimens during the bainitic transformation at 330 °C: (a) volume strains and (b) bainitic transformation rates.

As shown in Figure 6a, for the specimens transformed without stress, the volume strains are relatively small. When the uniaxial compressive stress of 140 MPa is imposed, the volume strains change faster, and the final strains are larger than those without stress, indicating that the amount of bainitic transformation increases with the stress. This is consistent with the result in Table 2. Figure 6b shows the changing rate of the volume during the isothermal holding at 330 °C, which represents the bainitic transformation rate. Compared to the specimens without stress, the maximum speeds of the bainitic transformation in the specimens with stress apparently increase, and the time corresponding to the peak speeds decrease by at least 1000 s; this demonstrates that the bainitic transformation is obviously accelerated by stress.

In addition, TP strain along the axial direction can be calculated by Equation (3) [2,3] and is shown in Figure 7.

$$\varepsilon_P = \varepsilon_L - 1/3 \times (\Delta V/V) \quad (3)$$

where  $\varepsilon_P$  is the TP strain, and  $\Delta V/V$  is the volume strains. As shown in Figure 7, the TP strains are very small for the specimens without stress, while they show a clear increase in the specimens with stress. More importantly, the TP strain increases with the austenitization temperature. It should be noted that very small TP strains evolve in the specimens without stress. This may be derived from the clamping stress or an inhomogeneous temperature distribution within the specimens. In general, the TP strains in the specimens without stress are much smaller than those in the specimens with stress.

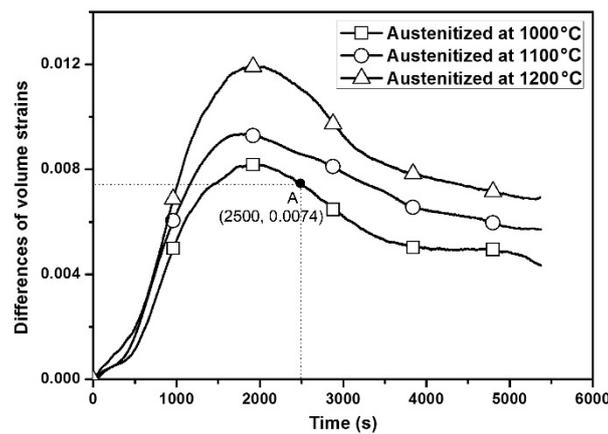


**Figure 7.** Transformation plasticity (TP) strain of different specimens during the bainitic transformation at 330 °C.

## 4. Discussion

### 4.1. The Promotion Degree of Stress

As shown in Figure 6a, bainitic transformation is promoted by the stress whether the austenitization temperature is high or low. However, the promotion degree is different. In order to quantitatively evaluate the promotion degree of the stress on bainitic transformation under different austenitization temperatures, the differences in volume strains during the isothermal holding at 330 °C between the specimens with stress and those without stress are calculated based on the data given in Figure 6a (see Figure 8). For example, the curve marked with squares in Figure 8 is the difference in volume strain between the specimen 1000-stress (the red curve in Figure 6a) and the specimen 1000-nos (the black curve in Figure 6a) *versus* time during the isothermal holding at 330 °C. It represents the difference in the amount of bainitic transformation between the two specimens because the volume strain quantitatively represents the amount of bainitic transformation. The abscissa (2500 s) and ordinate (0.0074) of point A in Figure 8 indicate that the volume strain of the specimen 1000-stress is 0.0074 higher than that of the specimen 1000-nos after 2500 s from the onset of the isothermal holding. Larger difference in volume strains indicates a larger difference in the amount of bainitic transformation. It is obviously observed in Figure 8 that the difference in volume strains is larger at higher austenitization temperatures. Therefore, the difference in the amount of bainitic transformation between the specimen with stress and that without stress is larger at higher austenitization temperatures. The measurement of bainite amount (Table 2) also indicates this changing rule. Therefore, it is reasonable to conclude that the promotion degree of stress on bainitic transformation increases with the austenitization temperature.



**Figure 8.** TP strain of different specimens during the bainitic transformation at 330 °C.

The varying promotion degree of stress on bainitic transformation under different austenitization temperatures is related to the prior austenite state (austenite grain size and GB area). Firstly, a larger grain size should be beneficial to enhance the promotion effect of stress. It has been confirmed that the growth of bainite is promoted by the stress [2–5,11], so the bainite sheaves grow to a longer size under the effect of stress. This is consistent with the present result (Figure 3). However, the prior austenite GB is a strong obstacle for the growth of bainite, so the GB hinders the promotion degree of stress. In a small austenite grain, the space for the bainite to grow is small, and the growth of bainite sheaves is easily hindered by the GB, so the growth of the bainite sheaves has already ceased before the stress could play a significant role in promoting the growth of bainite sheaves. In other words, the promotion degree of the stress is small in a small austenite grain. On the contrary, in a big austenite grain, there is enough space for the growth of bainite sheaves. Therefore, the stress can promote the growth of bainite sheaves for a longer time and the promotion degree of the stress is large in a big austenite grain. Secondly, a small GB area is disadvantageous to the promotion effect of stress. This is because the number of nucleation site of bainite decreases with the decrease of GB area. Therefore, the stress promotes less bainite nuclei, and the total promotion effect of stress is weakened. These two factors (prior austenite grain size and GB area) together affect the promotion degree of stress. Figure 4 shows that the increase in austenite grain size is accompanied by the decrease in the GB area when increasing the austenitization temperature, and there is a competition between the two factors. The results in Figure 8 and Table 2 show that the promotion degree of stress is larger at higher austenitization temperatures, indicating that the prior austenite grain size has a much more significant effect on the promotion degree of stress than the GB area. Another important reason for the larger role of the stress in the specimens with higher austenitization temperature is that the yield strength of the supercooled austenite decreases at higher austenitization temperatures due to larger austenite grains size according to the Hall–Petch Effect. Thus, the relation of the stress applied and the yield strength of the supercooled austenite is higher, leading to stronger promoting effect of mechanical driving force on selected variant growth.

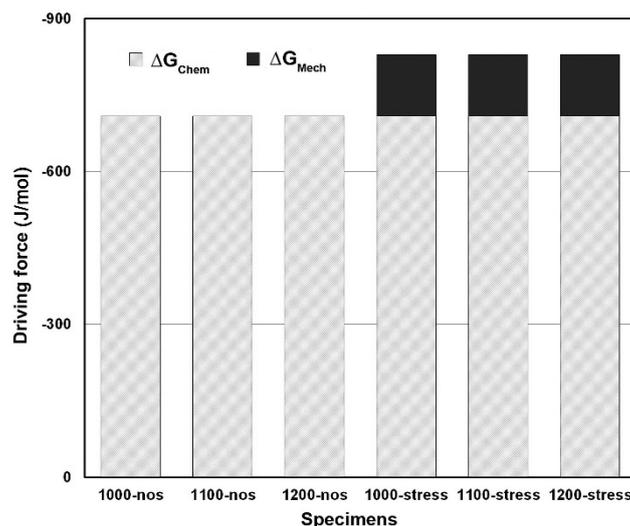
#### 4.2. The Factors Determining the Promotion Degree of Stress

The mechanical driving force provided by the stress can be calculated by the following equation [11]:

$$\Delta G_{\text{Mech}} = \sigma/2 \times [s \times \sin 2\phi - \delta(1 + \cos 2\phi)] \quad (4)$$

where  $\Delta G_{\text{Mech}}$  is the mechanical driving force,  $\sigma$  is the magnitude of the applied stress,  $\phi$  is the angle between the stress axis and the normal to the habit plane,  $s$  (about 0.26) is the shear strain of invariant plane strain (IPS) associated with the formation of bainite, and  $\delta$  (about 0.03) is the dilatational strain of IPS [20–23]. The maximum mechanical driving force (the corresponding value of  $\phi \sim 42^\circ$ ) is estimated

according to Equation (3), and the chemical driving force ( $\Delta G_{\text{Chem}}$ ) is determined by using the software of MUCG 83.Mod [22,24,25]. The results are shown in Figure 9. The maximum  $\Delta G_{\text{Mech}}$  is 113 J/mol for an applied stress of 140 MPa. The chemical driving force is estimated to be 709 J/mol for the tested steel at the isothermal temperature of 330 °C. It should be noted that at least 12 different variants of bainitic ferrite can form from one parent austenite orientation in a stress-free state; thus, there are at least 12 different values of  $\Delta G_{\text{Mech}}$  for one stress. An accurate calculation of mechanical driving force should consider all variants. The purpose here is to indicate that the proportion of  $\Delta G_{\text{Mech}}$  in the total driving force ( $\Delta G_{\text{Mech}} + \Delta G_{\text{Chem}}$ ). The maximum  $\Delta G_{\text{Mech}}$  (the corresponding value of  $\phi \sim 42^\circ$ ) represents the ultimate promoting ability of stress on bainitic transformation. Therefore, the maximum  $\Delta G_{\text{Mech}}$  is selected here as a representative of mechanical driving force. According to other studies [3,4], the maximum  $\Delta G_{\text{Mech}}$  can be used to qualitatively calculate the proportion of  $\Delta G_{\text{Mech}}$  in the total driving force. As mentioned in Section 1, the existing studies suggested that the promotion degree of stress on bainitic transformation is determined by the proportion of mechanical driving force in the total driving force. However, in the present study, the proportion of the mechanical driving force (13.7%) is the same in all of the specimens with stress, but the promotion degree of the stress on bainitic transformation increases with austenitization temperatures (Table 2 and Figure 8). Therefore, it can be concluded that the mechanical driving force provided by the stress is not the only factor that determines the promotion degree of stress on bainitic transformation. The results in the present study suggest that the grain size and the yield strength of prior austenite are other important factors.



**Figure 9.** Chemical driving force ( $\Delta G_{\text{Chem}}$ ) for bainitic transformation at 330 °C in the tested specimens and mechanical driving force ( $\Delta G_{\text{Mech}}$ ) provided by a stress of 140 MPa for the bainitic transformation.

#### 4.3. TP Strain

The growth of a bainite plate causes a shape deformation, which is an IPS with a large shear strain of 0.26 and a small dilatational strain of 0.03 [20–23]. TP strain is the accumulation of the shear strain [2]. Without the effect of the stress, the platelets of bainite may grow in many different orientations in a polycrystalline specimen. It is then probable that, for every shear, there is somewhere an opposing shear of equal magnitude [2–4]. As a result, the shear strain of the IPS cancels out, and the TP strain is barely detected [2–4]. According to Equation (4), when an axial stress is imposed on the specimens, the mechanical driving force for different bainite variants is not the same because of the varying value of  $\phi$ . The bainitic variants complying with the stress are promoted, while others are not. Therefore, variant selection occurs under the effect of stress, which has been confirmed in many studies [2,3,26–28]. In this case, the shear strain of the IPS does not cancel out and TP strain is detected. Figure 3 shows that stress makes the orientation of bainite sheaves much more uniform when the austenitization temperature is

higher. This is expected since the role of stress in favoring the growth of certain orientations of bainite sheaves becomes more significant with a higher austenitization temperature as mentioned above. Therefore, the TP strain increases with the austenitization temperature. Anisotropic volume changes are generally an unfavorable effect [5,13]. In order to minimize the anisotropic volume changes brought about by phase transformation in steels, the austenitization temperature can be decreased. In addition, TP strain is associated with the variant selection. The larger the TP strain is, the stronger the variant selection is. So it may be predicted that the variant selection caused by stress is stronger when the austenitization temperature is higher.

## 5. Conclusions

In the present study, thermal simulation experiments with different stress states and different austenitization temperatures were conducted. The varying effects of uniaxial compressive stress on the bainitic transformation under different austenitization temperatures were analyzed in detail. The results show that the promotion degree of stress on bainitic transformation increases with the austenitization temperature due to the larger prior austenite grain size as well as the stronger promoting effect of mechanical driving force on selected variant growth at higher austenitization temperatures. The mechanical driving force provided by the stress is not the only factor that determines the promotion degree of stress on bainitic transformation. The grain size and the yield strength of prior austenite are other important factors. Moreover, the TP strain increases with the austenitization temperature.

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**Author Contributions:** Guang Xu and Mingxing Zhou conceived and designed the experiments; Mingxing Zhou performed the experiments; Mingxing Zhou and Qing Yuan analyzed the data; Li Wang contributed materials tools; Mingxing Zhou wrote the paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

LSCM	high temperature laser scanning confocal microscopy
SEM	scanning electron microscope
TP	transformation plasticity
GB	grain boundaries
BF	bainitic ferrite
RA	retained austenite
M	martensite

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