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Effect of Ultrasonic Nanocrystal Surface Modification Treatment at Room and High Temperatures on the High-Frequency Fatigue Behavior of Inconel 718 Fabricated by Laser Metal Deposition

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Abstract: In this work, the effect of ultrasonic nanocrystal surface modification (UNSM) treatment at room and high temperatures (RT and HT) on the high-frequency fatigue behavior of Inconel 718 alloy fabricated by laser metal deposition (LMD) process was experimentally investigated. UNSM treatment at RT and HT modified a surface morphology and produced a nanostructured surface layer with a thickness of approximately 120 and 140 μm , respectively. The surface roughness of the untreated sample was reduced, while the surface hardness was notably increased after the UNSM treatment at RT and HT. Both increased with increasing the UNSM treatment temperature. Fatigue behavior of the untreated samples at various stress levels was slightly improved after the UNSM treatment at RT and HT. This is mainly due to the formation of a fine grained nanostructured surface layer with reduced porosity and highly induced compressive residual stress. Fatigue mechanisms of the samples were comprehensively discussed based on the quantitative SEM fractographic analysis.

Keywords: Inconel 718; additive manufacturing; residual stress; fatigue behavior; ultrasonic nanocrystal surface modification



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1. Introduction

The introduction of laser additive manufacturing (LAM) technologies offers solutions close to the final shape of engineering components that reduce the costs and time for manufacturers [1]. To achieve similar advantages with traditionally manufactured materials, various metallic materials and their alloys were fabricated by various LAM technologies [2,3]. Nowadays, laser metal deposition (LMD) fabricated components have been significantly developed and showed a possibility of being used in various key industries. The main advantage of the LMD process compared to other analogical LAM processes is the possibility of building large scale parts at high manufacturing rates. In most cases, the LMD process of Inconel 718 alloy is considered among the potential materials to be used in the aerospace industry.

Inconel 718 is a Ni-base alloy that is widely used in the aerospace industry requiring a high corrosion-resistance and high temperature fatigue creep-rupture properties up to 650 °C due to the presence of a γ solid supersaturated solution matrix [4]. LMD fabricated Ni-base alloys are attractive for the major aircraft manufacturers because of the high deposition rate and multiple powder feeders of the LMD process. Nowadays, the majority of aircraft manufacturers have put a lot of effort into reducing the weight of the aircraft by replacing conventionally manufactured components with LMD fabricated components [5]. It should be noted that jet engine components made of Inconel 718 alloy are designed to be operated for a long time at high frequencies. However, some jet engine components may

fail earlier than expected service lifespan because of high-frequency vibration. For example, Yakui and Shuxiang reported that a high-frequency vibration led to a shortened service lifespan of jet engine blades due to fatigue damage caused by fatigue crack initiation and subsequent crack propagation [6]. It is a well known fact that such fatigue failures of jet engines have a significant effect on aircraft reliability and flight safety. For these reasons, it is required to investigate the fatigue behavior of Inconel 718 alloy fabricated by LMD as major aircraft manufacturers have already adopted it for jet engine components. The simplest approach to increase safety features is a microstructural modification of jet engine materials by the application of thermal, chemical and mechanical surface modification processes. Numerous investigations on the effectiveness of surface modification processes were performed to improve the fatigue performance of jet engine components [7–10]. For instance, Chamanfar et al. investigated the metallurgical and mechanical performance of jet engine turbine discs made of Inconel 718 alloy after the shot peening process [11]. It was found that the deformed layer in the near-surface of jet engine components played an important role in increasing mechanical characteristics. Inconel 718-made turbine blade parts fabricated by the LAM process were studied to evaluate the effect of various surface peening processes [12]. It was found that the adverse surface defects can be significantly eliminated and they favorably affect the performance of turbine blades. Mazzucato and co-authors concluded that the LMD fabricated Inconel 718 samples demonstrated similar mechanical properties as casting materials by controlling and optimizing the main parameters [13]. They stated that the reason for improving the mechanical properties of LMD fabricated Inconel 718 samples was due to the increased laser power. Although the LMD process has many advantages, some unavoidable disadvantages, such as porosity, surface defects, etc., may weaken the mechanical properties of the materials.

It is commonly known that surface modification, which refines grains and introduces compressive residual stress may lead to significant improvements in the various properties of materials. It has been reported in a previous study that laser shock peening (LSP) improved the strength and ductility of the LMD fabricated samples made of Inconel 718 alloy [14]. It was concluded that surface severe plastic deformation closed pores on the surface and transformed tensile residual stress into compressive residual stress. Wang and Shi investigated the influence of ultrasonic impact peening (UIP) on the mechanical properties of the LMD fabricated Inconel 718 alloy [15]. They used a novel hybrid approach to achieve superior mechanical properties, where the UIP process was applied to each deposited layer after cooling (less than 100 °C). It was found from this investigation that a combination of the LMD and UIP processes showed the possibility of significantly increasing yield strength and ultimate tensile strength of LMD fabricated materials.

Ultrasonic nanocrystal surface modification (UNSM) treatment has been already applied to various metallic and ceramic materials manufactured by various additive manufacturing processes to improve their fatigue, tribological, corrosion, and other properties [16–19]. In our previous study, it was reported that the UNSM treatment under various parameters improved the rotary bending fatigue (RBF) behavior of the LMD fabricated Inconel 718 alloy [20]. This study aims to improve the high-frequency fatigue behavior of the LMD fabricated Inconel 718 alloy by UNSM treatment at room and high temperatures (RT and HT). Thus, considering the current attempt and findings of the study it can be possible to replace traditionally manufactured aerospace components made of Inconel 718 alloy with the LMD fabricated aerospace components made of Inconel 718 alloy.

2. Materials and Methods

2.1. LMD Process and Sample Preparation

In this study, an additive manufacturing machine (LASERTEC 65 3D HYBRID, DMG Mori Seiki Co., Ltd., Nagoya, Japan) was used to fabricate the samples. A schematic view of the LMD process can be seen in Figure 1a. The main parameters of the LMD process are optimized as follows: laser power of 1600 W, scanning speed of 900 mm/min, layer thickness of 0.80–0.90 mm, laser nozzle size of 3 mm, laser spot size of 30 µm and particle

sizes ranged between 50 μm and 110 μm . The powder particles of Inconel 718 alloy that was used to fabricate the samples were observed by scanning electron microscopy (SEM) as shown in Figure 1b. The chemical composition of Inconel 718 alloy was listed in Table 1. It should be noted here that the as-printed LMD samples have a relatively rough surface, which has a detrimental effect on fatigue behavior. Most of the LMD fabricated aerospace components tend to be subjected to post-processes in order to reduce surface roughness. Figure 1c shows the LMD fabricated samples, which were machined using a lathe machine.

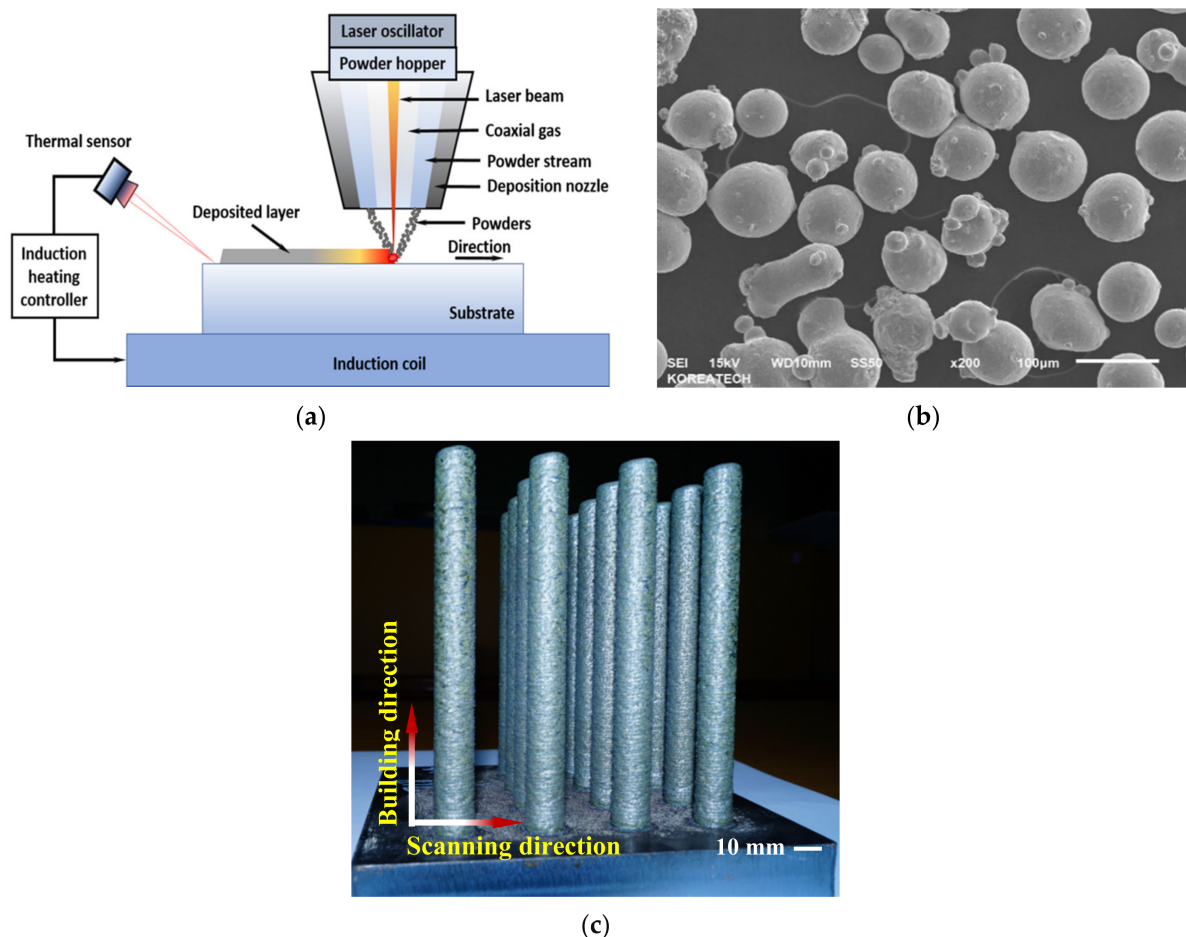


Figure 1. Schematic view of LMD process (a), SEM image of the particles (b) and LMD fabricated samples (c).

Table 1. Chemical composition of Inconel 718 alloy fabricated by LMD process.

Elements	Cr	Mo	Nb	Fe	Ti	Si	Mn	C	P	Ni
wt.%	19.0	3.0	5.0	18.0	1.0	0.2	0.08	0.05	0.02	Bal.

2.2. Surface Modification

UNSM treatment introduces surface severe plastic deformation at the surface layer with a certain depth (see Figure 2). The main advantages and disadvantages of the UNSM treatment can be found in our previous studies [21,22]. UNSM treatment parameters that were optimized in this study are listed in Table 2. Moreover, it should be noted here that UNSM treatment was applied to the LMD fabricated Inconel 718 samples at RT ($\sim 24^\circ\text{C}$) with an oil-spray and at HT ($\sim 400^\circ\text{C}$) without oil-spray. In addition, it is important to note here that an increase in temperature of UNSM treatment may further increase the mechanical properties of the LMD fabricated Inconel 718 samples due to the further refined

grains. To increase a temperature up to 400 °C, a halogen lamp (HCVD, Heat-Tech Co., Ltd., Kobe, Japan) was used. The actual temperature was controlled using a non-contact pyrometer (OPTIC CT, Optris GmbH, Berlin, Germany).

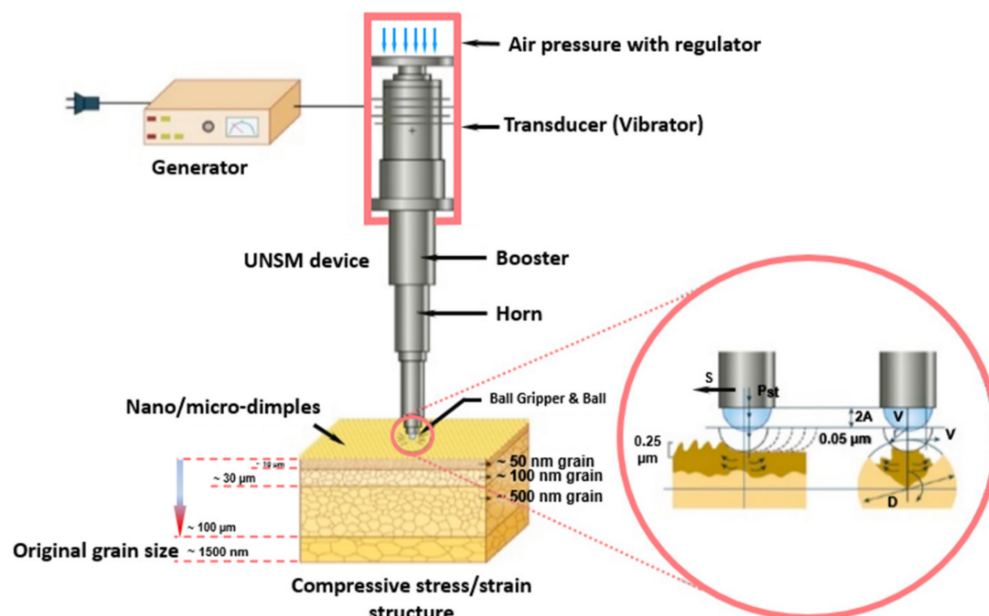


Figure 2. Schematic view of a UNSM treatment.

Table 2. Main parameters of UNSM treatment.

Frequency (kHz)	Amplitude (μm)	Feed-Rate (mm/rev)	Load (N)	Ball Material	Ball Diameter (mm)
20	30	0.03	50	WC	2.38

2.3. Fatigue Behavior

The fatigue behavior of the untreated and UNSM-treated at RT and HT samples was investigated using an ultrasonic fatigue tester (UFT) at a frequency of 20 kHz, a stress ratio of $R = -1$ and RT. The samples were subjected to cyclic axial loading. During the fatigue test, a high-frequency tends to raise the temperature of the samples. Due to this fact, all the samples were cooled down using an air cooling system and also an intermittent pulse-pause loading sequence with a range of 0.3 and 3 s. The schematic view of the UFT sample can be seen in Figure 3, where the UNSM-treated area is shown in blue. The fatigue behavior of the samples was investigated by establishing a classic breakage-failure fatigue test criterion for both the fractured and run-out samples as the failure criterion may lead to significant differences in the fatigue testing (S-N) results. The fatigue tests ran continuously until the samples fractured or the number of fatigue cycles reached up to 10^8 , which is known as a very high cycle fatigue (VHCF) regime. The fatigue tests at each stress level were repeated three times to minimize the effect of fatigue behavior scatter.

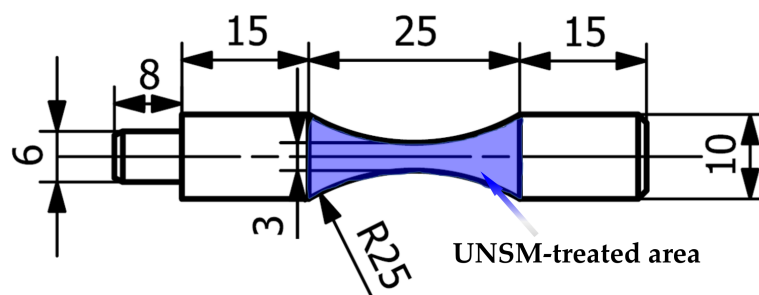


Figure 3. Schematic view of UFT sample.

2.4. Sample Characterization

The surface roughness of the samples was measured using a profilometer (SJ-210, Mitutoyo, Kanagawa, Japan) in accordance with the ASTM D7127 standard. The hardness (surface and depth profiles) was measured using a micro-Vickers tester (MVK-E3, Mitutoyo, Kanagawa, Japan) in accordance with the ASTM E384-89 standard. The surface and fractured surface morphologies were investigated by SEM (JSM-6610LA, JEOL, Tokyo, Japan). Surface residual stress was measured using an X-ray diffractometer (HyPix-3000, Rigaku, Tokyo, Japan) in accordance with the SAE J784a standard. The cross-sections were investigated by electron backscattered diffraction (EBSD: Tescan MAIA 3 Oxford Instruments Nordlys, Oxford, UK).

3. Results and Discussion

3.1. Surface Roughness and Hardness

The surface roughness of any solid material has a crucial influence on fatigue behavior as it affects the crack initiation and propagation phenomena. LMD fabricated materials tend to have high surface roughness along with unsatisfactory mechanical properties due to the non-equilibrium nature of LAM processing [23]. In this regard, the surface roughness of the LMD fabricated components is controlled by machining or polishing because a low surface roughness is more preferred to extend the fatigue life of the structural components [24]. Low surface roughness can be achieved by the application of various surface modification processes leading to a removal of high surface valleys and peaks, and elimination of pores and defects. It should be mentioned here that, the surface roughness of materials can be controlled by optimizing the main parameters of UNSM treatment. In Table 3, it is clearly seen that the surface roughness of the untreated sample was about R_a 0.48 μm and R_z 2.84 μm , which was lowered down to R_a 0.19 μm and R_z 1.07 μm , and R_a 0.30 μm and R_z 1.62 μm after UNSM treatment at RT and HT, respectively. It can be attributed to the removal of high surface valleys and peaks, and the elimination of pores and defects after UNSM treatment at RT and HT. On the other hand, a slight increase in surface roughness after UNSM treatment at HT sample in comparison with that of the UNSM-treated at RT sample may be explained with the presence of small defects, which are discussed in the next section. Pegues et al. investigated the effect of surface roughness on the fatigue behavior of the LAM samples [25]. The authors pointed out that a smoother surface improved the fatigue behavior, where the main mechanism is associated with homogeneous surface integrity that delayed the initiation and propagation of fatigue cracks.

Table 3. The surface roughness results.

Samples	Surface Roughness (R_a and R_z)									
	1st Test		2nd Test		3rd Test		4th Test		Average	
	R_a	R_z	R_a	R_z	R_a	R_z	R_a	R_z	R_a	R_z
Untreated	0.41	2.77	0.51	2.84	0.49	2.67	0.50	3.09	0.48	2.84
UNSM at RT	0.17	0.87	0.19	1.10	0.19	1.11	0.23	1.19	0.19	1.07
UNSM at HT	0.26	1.42	0.30	1.54	0.35	1.83	0.29	1.70	0.30	1.62

Another important property for controlling the fatigue behavior of the LMD fabricated materials is hardness. As shown in Figure 4, the surface hardness of the untreated sample was about 247 HV, which was increased up to about 408 HV and 418 HV after UNSM treatment at RT and HT with an effective hardened layer thickness of 300 μm and 350 μm , respectively. The UNSM-treated at HT sample demonstrated a higher hardness throughout the thickness of the hardened layer, except at the thickness of a hardened layer of 200 μm , than that of the UNSM-treated at RT sample. An increase in hardness of materials subjected to various surface modification technologies may be attributed to the work-hardening effects, such as grain refinement, generation of twinning microstructure and surface severe plastic deformation [26]. In addition, the elimination of pores on the surface and subsurface after UNSM treatment at RT and HT also plays an important role in increasing the hardness of LAM materials. Recently, a correlation between surface hardness and pores of the LAM samples was systematically investigated [27]. It was found that eliminated pores led to an increase in surface hardness. In general, the higher hardness and deeper hardened layer of the LAM sample the longer the fatigue life [28]. Deep hardened layers tend to shift a crack initiation site to the subsurface of the LMD fabricated samples. For instance, initiation and further free propagation of fatigue cracks might be delayed due to the formation of a hardened layer.

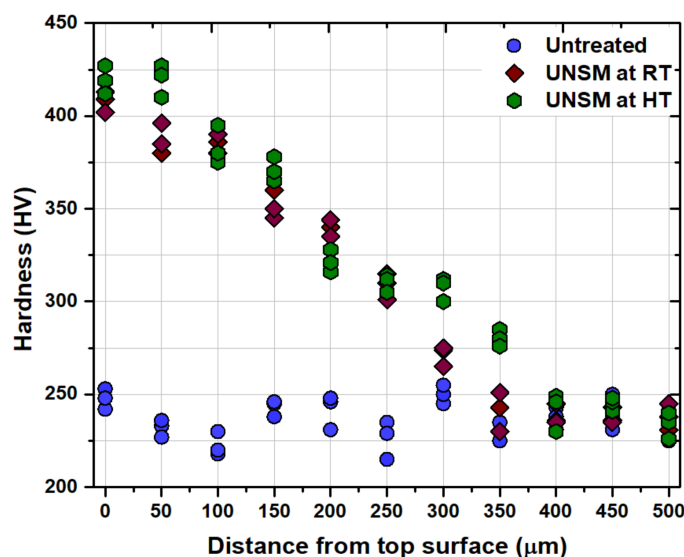


Figure 4. Hardness results of the untreated, UNSM-treated at RT and HT samples.

3.2. Surface Morphology

Figure 5 shows the surface morphology of the untreated, UNSM-treated at RT and HT samples. It is obvious from Figure 5a that the untreated sample has surface and inner microstructure defects indicated by yellow arrows despite severe polishing with fine grit SiC sandpaper (2000 grit). The diameter of the single and interconnected pores was in the range of 10 μm to 60 μm . Figure 5b, c shows the surface morphology of the UNSM-treated RT and HT samples, which led to a smooth surface morphology due to high-frequency continuous bombardment with a combination of static and dynamic loads [29]. It should be noted here that UNSM treatment at RT and HT significantly reduced the surface roughness of the untreated sample, where the latter one was not able to remove small-sized defects and pores (shown by yellow arrows), which led to an increase in surface roughness in comparison with the UNSM-treated at RT sample, where both were still lower than that of the untreated one. The surface defects, such as cracks, pores, etc., have a significant effect on the fatigue behavior of LAM materials. For example, Hu et al. investigated the effects of surface and microstructural defects of the LAM samples on fatigue behavior [30]. It was concluded that the location and size of defects strongly affect the fatigue behavior of the LAM samples. They also mentioned that the surface defects demonstrated a lower fatigue resistance

as compared to the subsurface defects. Elimination of surface and subsurface defects may not only improve the fatigue behavior of the LMD components but also increase the mechanical properties. Nasab et al. investigated the effects of eliminated surface defects of AlSi10Mg alloy manufactured by LAM on mechanical properties and fatigue resistance [31]. It was concluded that a reduction of surface defects significantly increased the fatigue resistance. Therefore, it is important to control the surface morphology to achieve a better fatigue behavior of LMD fabricated components. Further, comparative analyses are shown in Figure 5b, c exhibited that the UNSM-treated at RT sample had a smoother surface morphology, while the surface morphology of the UNSM-treated at HT sample had a few small defects. These findings agree with the results of surface roughness reported in Table 3, where the UNSM-treated at HT sample showed a higher surface roughness compared to that of the UNSM-treated at RT sample. The main reason for the incomplete elimination of surface defects and pores after UNSM treatment at HT may be attributed to the formation of fault zones that absorbed insufficient energy during UNSM treatment resulting in a lowering of the bonds between particles.

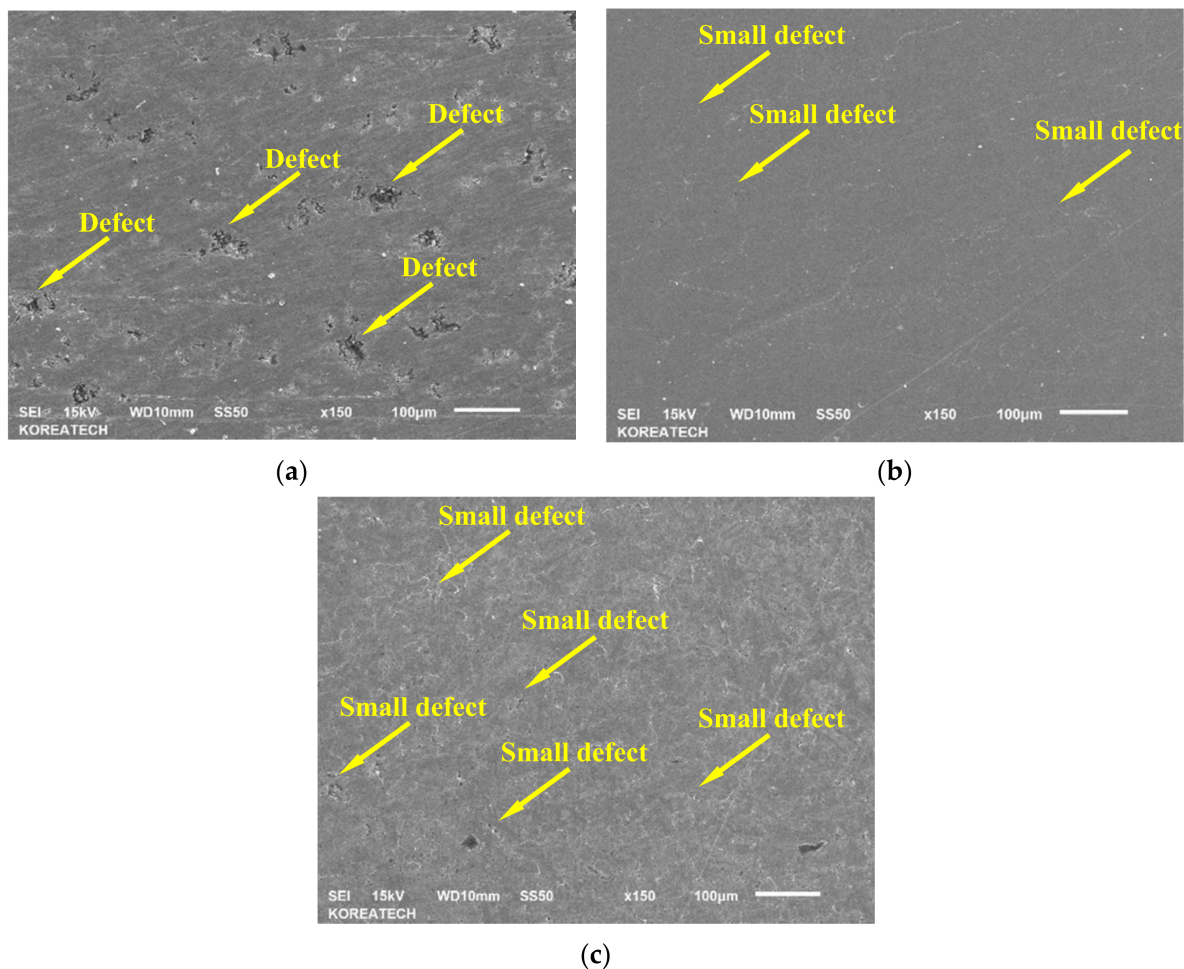


Figure 5. Comparison in surface morphology of the untreated (a), UNSM-treated at RT (b) and UNSM-treated at HT (c) samples.

3.3. Residual Stress

Residual stress is one of the key properties, which determines the fatigue behavior of the materials. Early initiation and further propagation of micro-cracks in the structures depend on residual stress. In general, the materials with tensile residual stress mostly demonstrated poor fatigue behavior as tensile residual stress is not able to resist cracks from being initiated. Some studies have shown that an introduction of high compressive

residual stress tends to improve the fatigue behavior of materials [32–34]. The surface residual stress results of the untreated and UNSM-treated samples, which were measured three times in randomly selected areas by the XRD method, are displayed in Figure 6. It can be seen that the tensile residual stress of the untreated sample was about 43.75 MPa, while the UNSM-treated at RT and HT samples demonstrated a compressive residual stress of about -977.5 MPa and -1113.75 MPa, respectively. Such a result for the untreated sample may occur with the laser scan strategy of the LMD process where re-melting and overlapping factors may lead to increased residual stress on the surface. Analogical results for the LMD fabricated samples were found by Kemerling and co-authors [35]. On the other hand, the beneficial effects of UNSM treatment can be explained by surface severe plastic deformation and the formation of a nanostructured surface layer. In detail, during the UNSM treatment, a highly induced plastic deformation will increase protection for elasticity recovery and this fact led to the retention of compressive residual stress. Furthermore, as shown in Figure 6, the compressive residual stress after UNSM treatment in the HT sample was higher compared to that of the UNSM-treated RT sample. These phenomena can be explained by the temperature effect, where a phase transformation plays an important role.

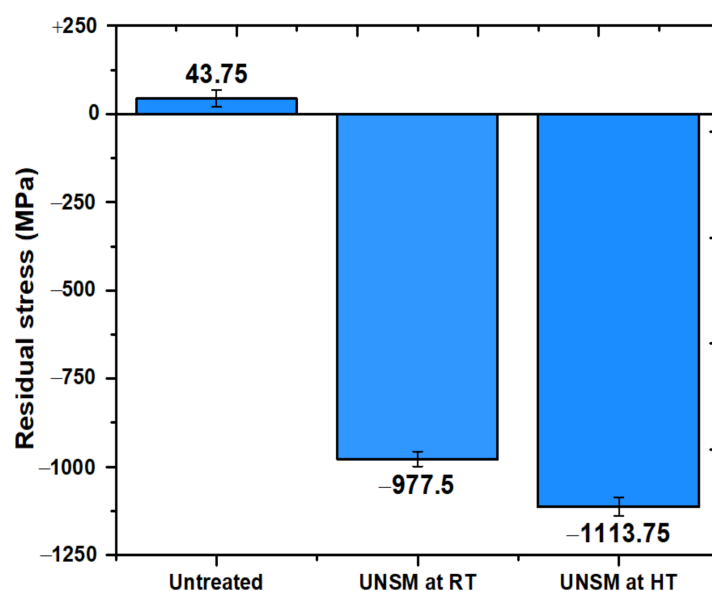


Figure 6. Comparison in residual stress of the untreated, UNSM-treated at RT and HT samples.

3.4. EBSD Analysis

Figure 7 shows the EBSD maps of the untreated, UNSM-treated at RT and UNSM-treated at HT samples. It is confirmed that the untreated sample contains coarse grains, which were refined into nano-sized grains with an approximate thickness of $120\text{ }\mu\text{m}$ and $140\text{ }\mu\text{m}$ from the top surface after UNSM treatment at RT and HT, respectively. The grain size within the nanostructured surface layer of the UNSM-treated at HT sample seems to be finer compared to that of the UNSM-treated at RT sample. Moreover, the thickness of the nanostructured surface layer of the UNSM-treated at HT seems thicker than that of the UNSM-treated at RT sample. An increase in temperature of UNSM treatment resulted in finer grain size and a thicker nanostructured surface layer. An increased hardness after UNSM treatment at RT and HT shown in Figure 4 may be mainly attributed to the formation of a nanostructured surface layer [20]. A high number of dislocations are reasons for strain hardening [36]. The main mechanisms of the formation of a nanostructured surface layer can be explained by the effect of surface severe plastic deformation [20]. The level of surface severe plastic deformation gradually reduced with increasing the depth from the top surface of the UNSM-treated at RT and HT samples. Furthermore, Figure 7c displayed the formation of severe plastic deformation at the grain boundary (indicated by yellow arrow) after UNSM treatment at HT. It can be pointed out that after UNSM treatment

at HT, the microstructure of the Inconel 718 alloy is slightly different compared to UNSM treatment at RT.

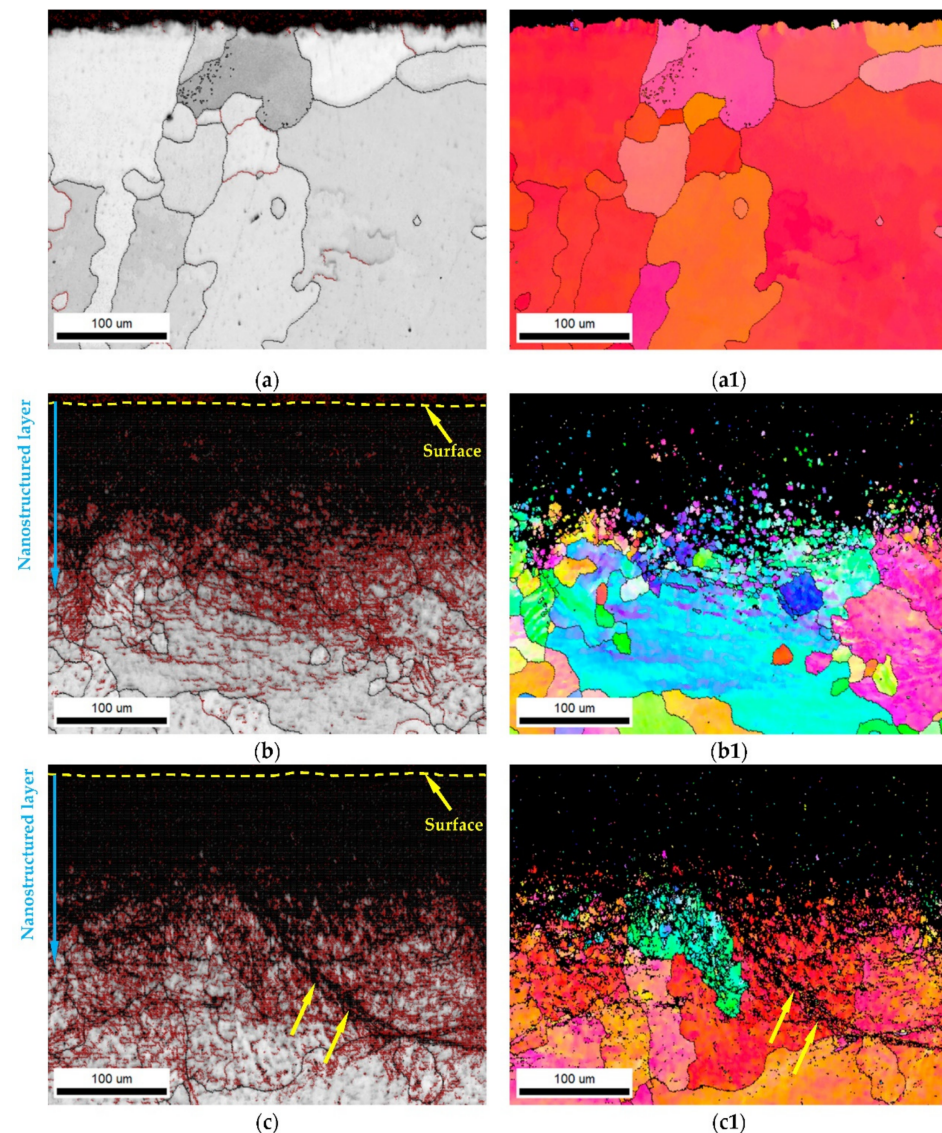


Figure 7. Comparison in EBSD results of the untreated (a,a1), UNSM-treated at RT (b,b1) and UNSM-treated at HT (c,c1) samples.

3.5. S-N Data

In order to confirm the applicability of LMD fabricated components to be implemented into the aerospace industry their fatigue life is required to be evaluated up to VHCF at various operating conditions. Comparison in fatigue behavior of the LMD fabricated Inconel 718 samples and subjected to UNSM treatment at RT and HT is presented in Figure 8. It is apparent that UNSM treatment at RT and HT improved the fatigue behavior of the untreated samples. However, the effect of UNSM treatment at RT and HT lessened in the low cycle fatigue (LCF) regime with increasing the stress level. Insignificant improvement in fatigue life of the LMD fabricated samples in the LCF regime after UNSM treatment at RT and HT may be attributed to the improved surface roughness, hardness, and yield strength [37]. It is believed that the relatively high surface roughness of the samples affected fatigue life in the LCF regime. The fatigue limit of the untreated sample was 233 Mpa, which increased up to 253 Mpa after UNSM treatment at RT and HT. No difference in the fatigue limit was found despite the UNSM-treated at HT sample having a higher surface hardness and compressive residual stress than that of the UNSM-treated at RT sample. It can be

associated with the reduced elongation of the UNSM-treated at HT sample. Moreover, high surface roughness with the presence of pores and defects affected the fatigue limit of the UNSM-treated at HT sample in comparison with the results of the UNSM-treated at RT sample. The introduction of high compressive residual stress significantly improves the fatigue behavior of LAM components by delaying crack propagation. Yan et al. investigated the effect of surface mechanical attrition treatment (SMAT) on the fatigue behavior of the samples manufactured by LAM [38]. They pointed out that the nanocrystalline surface layer with a high number of grain boundaries improved the mechanical properties and thereby improved the fatigue behavior. Moreover, it is of interest to discuss here the improved RBF behavior of the LMD fabricated Inconel 718 alloy after UNSM treatment. It was found that UNSM-treated at HT samples had a higher fatigue limit than that of the UNSM-treated at RT samples [20]. The fatigue limit of Inconel 718 alloy determined by RBF was higher than that of the fatigue limit determined by UFT due to the different types of stress distribution across the section of the samples and also loaded material volume (risk volume) [39]. In particular, the stress distribution of the hourglass-shaped sample increases at the surface and gradually decreases to zero in RBF testing, while the stress distribution remains constant across the section of the hourglass-shaped sample that leads to an early fatigue fracture. Shrestha et al. investigated the effect of bending and axial loading stress distribution on the fatigue behavior of LAM samples [40]. It was concluded that bending stress distribution demonstrated a longer fatigue life because of a lower crack propagation rate than that of the axial loading stress distribution. It can be concluded based on the findings that the UNSM treatment at HT of 400 °C was not good enough to significantly increase the fatigue limit of LMD fabricated Inconel 718 alloy samples. It can be attributed to the insufficiently improved mechanical properties of the samples. Hence, it is necessary to treat the LMD fabricated Inconel 718 alloy samples by UNSM treatment at HT of 500–900 °C to be able to observe the effectiveness of UNSM treatment at HT on the fatigue limit and life in comparison with the untreated and UNSM-treated at RT samples.

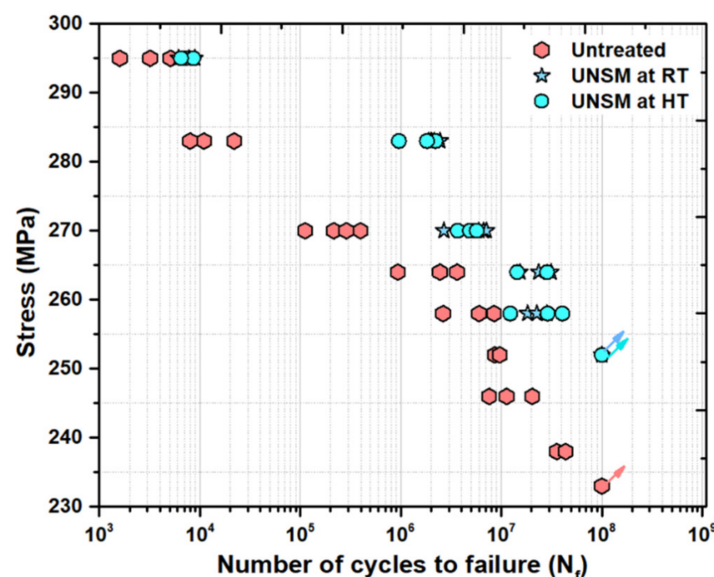


Figure 8. Comparison of UFT test results for the untreated and UNSM-treated at RT and HT samples.

3.6. Fractured Surface

SEM images of the fractured samples at a stress of 258 Mpa can be seen in Figure 9. It is clear from Figure 9a that the main fatigue crack of the untreated sample initiated from the surface and subsequently propagated into the subsurface. As the untreated sample has a coarse-grained structure, it is unable to resist the main fatigue cracks being initiated at the surface. Masuo and co-authors concluded that crack initiation at the surface of the LMD fabricated samples may be attributed to microstructural defects, such as pores, unmelted

particles, etc., [41]. As shown in Figure 9(a1), the main fatigue crack initiated at the surface due to the presence of pores with a diameter of about 7–8 μm . Yang et al. investigated the effect of surface pore size of SLM fabricated Inconel 718 alloy components on fatigue behavior [42]. It was concluded that a surface pore size with several micrometers may result in the initiation of fatigue cracks, which have a negative effect on the fatigue limit. Nevertheless, the fatigue behavior of the LAM samples can be improved by eliminating or reducing pores [43]. In the case of UNSM-treated at RT and HT samples, the main fatigue crack initiated from the subsurface with a depth of about 300 and 290 μm , respectively (see Figure 9(b1,c1)). The type of subsurface crack initiation defect for the UNSM-treated at RT and HT samples was hard inclusion with facets. A shift of crack initiation site of the UNSM-treated at RT and HT samples is mainly associated with the introduction of compressive residual stress, where the main mechanism is explained by the impossibility of initiations in the compressive deformed structure. Furthermore, it should be mentioned here that surface hardness and hardness with respect to depth may also influence on crack initiation site under high stress. These facts can be well argued with hardness results shown in Figure 4, where a hardened layer was achieved of about 300 μm . The surface hardness can also increase the resistance of crack initiation and their further propagation by shifting a crack initiation site from the surface to the subsurface, and also delaying crack propagation [44,45]. Moreover, a visible light green colored area shown in Figure 9a–c represents the final fracture surface. It is clearly seen from SEM images that the final fracture shape for the untreated, UNSM-treated at RT and HT samples was different. Earlier, the effect of LSP on the delay of fatigue crack propagation of the LAM fabricated sample was studied [46]. It was reported that an increase in the number of grain boundaries hinders the movement of the dislocations and thereby delays the crack propagation.

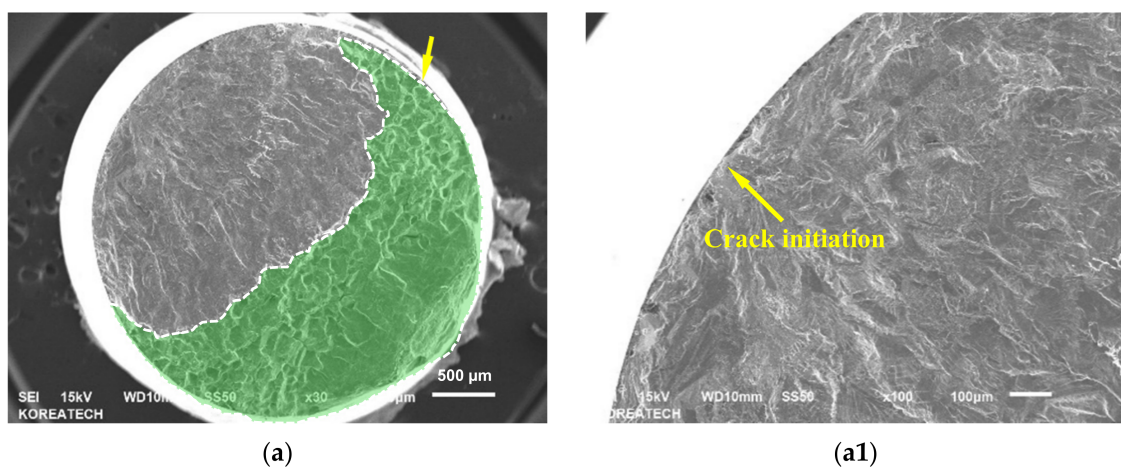


Figure 9. Cont.

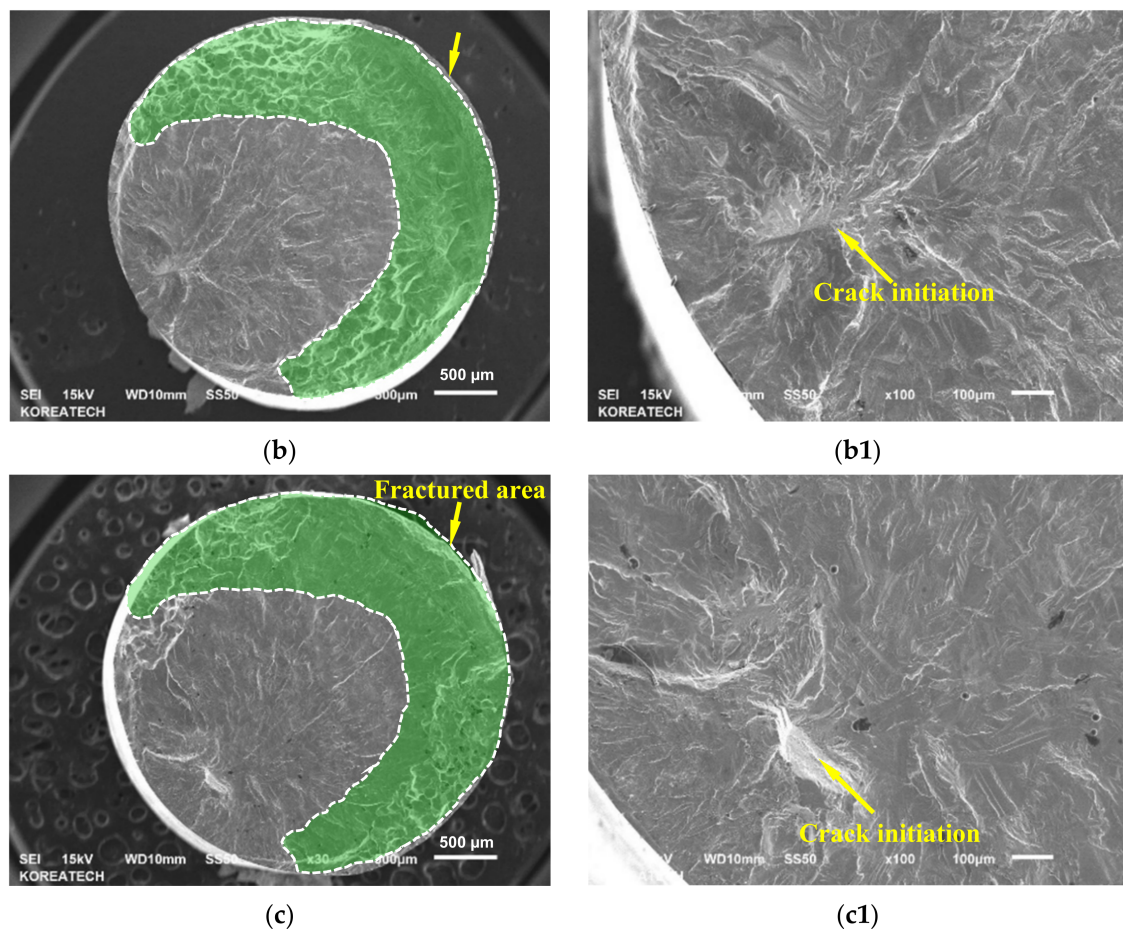


Figure 9. Comparison in fatigue fracture surface of the untreated (a,a1), UNSM-treated at RT (b,b1) and UNSM-treated at HT (c,c1) samples.

4. Conclusions

The current study addresses the effect of UNSM treatment at RT and HT on the high-frequency fatigue behavior of Inconel 718 alloy fabricated by LMD. The obtained results can be concluded as follows:

The surface roughness of the untreated Inconel 718 alloy reduced down to a Ra of 61% and 37%, a Rz of 62% and 43% after UNSM treatment at RT and HT, respectively. The surface hardness of the untreated Inconel 718 alloy increased by about 78% and 87% after UNSM treatment at RT and HT, respectively.

The surface morphology of the samples demonstrated that the surface pores and defects of the untreated Inconel 718 alloy were still visible even though the samples were machined and further severely polished.

Tensile residual stress of the untreated Inconel 718 alloy was transformed into compressive residual stress, which has a significant effect on the delay of fatigue crack initiation and propagation.

The formation of a nanostructured surface layer with a thickness of about 120 and 140 μm after UNSM treatment at RT and HT was confirmed.

The fatigue behavior of the untreated Inconel 718 alloy was improved after UNSM treatment at RT and HT, which shifted the fatigue crack initiation site from the surface into the subsurface. However, the surface finish after LMD affected the fatigue behavior of the Inconel 718 alloy.

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