論 文 の 要 旨(Abstract)

題 目：Evaluation for Solidification Cracking Susceptibility of Type 310S Stainless Steel using Laser Trans-Varestraint Test and Prediction of Solidification Microstructure using Multi-Phase Field Modeling
（レーザトランスバレストレイン試験法を用いたステンレス鋼 SUS 310S の凝固割れ感受性の評価とマルチフェーズフィールド法を用いた凝固組織予測）

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With the development of science and technology, laser beam welding (LBW), owning high power density, high efficiency, and ability to provide high welding speeds and lower distortions, has been widely used in the various fields. For the welding of austenite stainless steel, such as type 310S, solidification crack occurs as a contribution of solidification behavior and thermal strain which is determined by welding conditions, especially welding speed. At present, there are lots of studies regarding solidification crack, however, the research on the effect of high welding speed on solidification cracking susceptibility quantitatively during the LBW is few. Therefore, the solidification cracking susceptibility need to be under the discussion during LBW at different welding speeds.

High temperature ductility curve composed of the local critical strain and brittle temperature range (BTR) can quantitative evaluate solidification cracking susceptibility. In general, the occurrence of solidification crack is in the BTR where the ductility of material deteriorates in mushy zone. Therefore, it is necessary to study both the local critical strain and BTR in order to evaluate solidification cracking susceptibility comprehensively and precisely.

Until now, Shinozaki group has already developed U type hot cracking test with LBW to measure the local critical strain. However, an effective evaluation method to measure the BTR precisely is few during LBW. Thus, the author et al. develop laser Trans-Varestaint test in order to measure the BTR during LBW. In addition, the local critical strain and BTR are considered to be influenced by the morphology and distribution of the residual liquid metal at the terminal of solidification. Thus, it is necessary to obtain these indexes, like the morphology and distribution of the residual liquid, to understand solidification cracking mechanism. However, through experimental method, it is hard to measure these values due to high cooling rate. Therefore, the multi-phase field method as one of candidates can be employed to simulate the residual liquid distribution for predicting solidification phenomenon. In this thesis, the purpose is to develop a systematic method to evaluate solidification cracking susceptibility quantitatively and predict the real solidification phenomenon in order to under solidification cracking mechanism during LBW.

First, the Trans-Varestraint test during LBW is developed and evaluation method is investigated for measuring the BTR and further evaluating solidification cracking susceptibility quantitatively. For comparison, the traditional Trans-Varestraint test during gas tungsten arc welding (GTAW) is also carried out at welding speed of 0.2 m/min, same as that using LBW. The number density of solidification crack and total crack length per bead width using LBW are nearly the same as that using GTAW. The result shows the heat source between LBW and GTAW has a little influence on solidification cracking susceptibility. In order to further measure the BTR during LBW, temperature profile is measured by inserting an optical fiber radiation thermometer into the molten pool and the liquidus temperature is obtained under the help of in-situ observation method at welding speed of 0.2 m/min. However, the problem of temperature measurement using a thermometer is presented at high welding speed. Thus, measurement method of 2D temperature distribution by using a multi-sensor camera is introduced and used in order

to measure the BTR during LBW. The method to measure the temperature range of the crack is illustrated in detail. Finally, the temperature range of each solidification crack can be measured and the BTR is the maximum temperature range of the crack by using 2D temperature distribution. In addition, the ductility curve tendency is obtained by drawing the curve covering all of the temperature range of the crack.

Next, the influence of welding speed from 0.2 to 2.0 m/min on solidification cracking susceptibility is evaluated for type 310S stainless steel during LBW. The longest solidification crack occurs at the rear center of the molten pool at low welding speed of 0.2 m/min, however, it tends to appear at the side of molten pool at high welding speeds from 1.0 to 2.0 m/min. The number density of solidification crack and total crack length per bead width have a tendency to first increase and then keep stable with increasing welding speed. In order to measure a true BTR, the applicability and accuracy of measurement method of the 2D temperature distribution for measuring the temperature range of the crack are evaluated quantitatively. And the BTR is the average value under saturated augmented strain of 2.8 and 4.3 %. The result shows the BTR is almost the same at around 102 °C during LBW at welding speeds from 0.2 to 2.0 m/min. Finally, solidification cracking susceptibility could be evaluated comprehensively using the CST' calculated using the minimum local critical strain (ε_{min}) divided by the BTR. The CST' tends to decrease with increasing laser welding speed as a result of the same BTR and a decrease of ε_{min}. The result shows that solidification cracking susceptibility has a tendency of increase during LBW at different welding speeds from 0.2 to 2.0 m/min.

Then, the morphology and distribution of the residual liquid under different cooling rates are simulated using the multi-phase field method to predict real solidification phenomenon and understand solidification cracking mechanism during LBW at different welding speeds. The secondary dendrite arm spacing and primary dendrite tip radius in the calculation result by adjusting the calculation parameters, such as interfacial mobility and anisotropy of interfacial mobility, have agreement with those of liquid Sn quenched microstructure and KGT modeling, respectively. The effect of the parameters, such as interfacial mobility, interfacial energy, anisotropies of interfacial mobility and interfacial stiffness, on the length of the residual liquid region is investigated quantitatively. In order to verify the calculation result, the length of the residual liquid region is compared with that of the fracture surface of the solidification crack. The result shows the calculated length of the residual liquid is nearly the same as that of fracture surface by adjusting calculation parameters, like interfacial mobility and anisotropy of interfacial mobility. Therefore, the residual liquid distribution could be predicted precisely by verifying with experiment and optimizing calculation parameters.

According to the predicted result, the distribution of the similar residual liquid dot at the terminal of solidification under different cooling rates contributes to the same BTR during LBW at different welding speeds. However, the appearance of the relatively long residual liquid film in the region under higher cooling rates leads to a decrease in the minimum local critical strain during LBW at higher welding speeds. Therefore, comprehensively these factors cause an increase in the solidification cracking susceptibility of type 310S stainless steel during LBW at different welding speeds from 0.2 to 2.0 m/min. Moreover, based on this and previous calculation, the result shows the interfacial mobility tends to increase and anisotropy of interfacial mobility tends to decrease with increasing cooling rate. And it is possible to apply the recommended calculation parameters to predict real solidification phenomenon under various cooling rates.