INTRODUCTION
Friction bit joining is a new concept for spot joining, where a consumable joining bit is applied to the joining of two or more sheets (patent pending). This concept relies on a cutting step, where the bit cuts through the top layer (or layers) of material, followed by a joining step, where the bit and surrounding sheet materials are heated by friction and where the bit is consumed as filler material that joins the sheets together. At the end of the joining process, the spindle of the welding machine was stopped very rapidly and then restarted to separate the joining bit from the weld. The schematic drawing of this process is shown in Fig. 1. The objective of developing this new process is to produce defect-free spot welds with higher performance than the resistance spot welding and friction stir spot welding in the high strength steels and dissimilar combinations of steel and light metal. In general, the microstructure strongly affects the mechanical properties of the joint and is directly related to the reliability of the joint, but such metallurgical studies have not been done in this joining process. The purpose of this study is to examine the microstructure associated with the hardness in the joint of DP980 steel systematically.

EXPERIMENTAL
The base material used in the present study was DP980 steel, 1.4 mm in thickness. The DP980 steel has a duplex microstructure consisting of ferrite and martensite. The martensite fraction was about 64 vol% in the as-received state. The D2 tool steel was used as the joining bit. During the cutting procedure, the joining bit was rotated at a relatively slow speed 725 rpm, while during the joining operation the speed was increased to 1800 rpm. The joining bit was plunged into the sheet at 25mm/min during the cutting step, while 100mm/min was used during the joining operation. Microstructure of the joint was examined on a cross section of the joint etched with 5 vol% nitric acid + methanol solution by scanning electron microscopy (SEM). The Vickers hardness profile of the joint was measured on the cross section with 9.8N load for 10s.

RESULTS AND DISCUSSION
Macroscopic overview of the cross section is presented in Fig. 2(a). A defect-free joint is successfully produced. The microstructure of the joint is classified into seven regions: (1) the joining bit in the center of the joint, (2) the interface region just outside the bit, (3) the alternating bands located between the bit and the
interface region, (4) the fine equiaxed grain region closed to the interface region, (5) the TMAZ outside the fine equiaxed grain region, (6) the HAZ outside the TMAZ, and (7) the unaffected DP980 base material (BM). The alternating bands consist of the DP980 steel and the joining bit (Fig. 2(b)). The interface region mainly has the martensitic structure (Fig. 2(c)), which suggests that the maximum temperature is higher than the $A_3$ temperature in this region during joining. Fig. 2(d) shows the fine equiaxed grain region consisting of the fine equiaxed (ferrite + martensite) microstructure. The martensite fraction of this region was about 55%. The lath martensite with the ferrite matrix is found in the TMAZ, and its martensite fraction is about 50 %, as shown in Fig. 2(e). Both the fine equiaxed grain region and TMAZ would be heated up between $A_1$ and $A_3$ temperatures during joining. The difference in microstructure between them would be attributed to degree of recrystallization of the (ferrite + austenite) microstructure during joining step. The HAZ has roughly the same microstructure as BM, but the martensite was tempered in the HAZ during joining (Fig. 2(f)).

Typical Vickers hardness profile of the joint is given in Fig. 3. The DP980 base material has average hardness of about 300 HV, and average hardness of the joining bit is significantly high (about 700 HV). In the DP980 steel, the hardness profile mainly depended on the martensite fraction. The martensite fraction decreases from the interface region to TMAZ, which causes the reduction of hardness. The lowest hardness is found at the border between the HAZ and TMAZ. This could be explained by tempering of the martensite.