History of Bainite

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The classical paper on isothermal transformation of austenite by Davenport and Bain in 1930 (1) was reprinted in 1970 with a commentary by Paxton (2) to celebrate the 40th anniversary. It has now been reprinted again in Metall. Mater. Trans. in time for the 80th anniversary. It was there accompanied by a personal commentary by Bhadeshia (3) who emphasized the importance of the paper for the development of the diffusionless hypothesis of bainite formation.

It has often been stated that Davenport and Bain were the first to describe the microstructure now called bainite but already Mehl mentioned in his Hatfield memorial lecture in 1948 (4) that the structures "referred to by the generic term 'bainite', and which are formed at intermediate or low temperatures, are by no means new, for they were observed early in this century". As an example, Hultgren (5) in 1920 published micrographs of bainite in tungsten steels from specimens obtained by interrupted isothermal transformation. Also, a very extensive study of the microstructures obtained by isothermal transformation of steels was published by Robertson in 1929 (6) who published 42 micrographs, 36 of them showing bainite whereas Davenport and Bain, who published their work a year later, only presented two micrographs showing bainite. They did give reference to Robertson's work but emphasized that it appeared "since the inauguration" of their own work. In Bain's own account of the history, published in the "Sorby Centennial Symposium on the History of Metallurgy" (7), he described in detail how he got the idea of studying the isothermal transformation of austenite. From Paxton's excellent review it seems that the time was ripe for this kind of study and the motivation came from the growing interest in understanding hardening and tempering of steel. In view of this misinterpretation of the role of Davenport and Bain it may be interesting to examine their role in the development of the diffusionless hypothesis of bainite.

The main contribution by Davenport and Bain was probably to emphasize the advantage of studying the gradual development of the isothermal transformation products and to construct TTT diagrams as a means of summarizing the information on the gradual transformations as function of temperature. That was a revolutionary accomplishment. Today it is realized that pearlite and bainite have their own sets of C curves but for plain carbon steels they usually overlap and it is difficult to separate them. However, the TTT diagrams from Davenport and Bain show a second set of C curves at very low temperatures. They presented very few micrographs but added small symbols to the TTT diagrams to indicate the nature of the transformation products at various temperatures. For the lower C curves the symbol represents martensite and the symbol for acicular microstructure was placed at the lower part of the upper C curve. It is evident that Davenport and Bain interpreted the lower set of C curves as belonging to martensite and the upper set of C curves as representing pearlite at the higher temperatures and bainite at the intermediate temperatures.

Since Davenport and Bain gave reference to the paper by Robertson stating that he had "treated the microstructural aspects of a similar study in an excellent manner" it seems probable that they had also read his proposal of an increasing carbon solubility in ferrite at lower temperatures. In their own discussion they also described how, as the temperature is lowered, “the simultaneous separation of carbide and ferrite disappears and instead the trend of the allotropic change (austenite $\rightarrow$ ferrite) to sweep across a grain ahead of carbide separation becomes more and more marked down to the martensite reaction. .... This trend seems to grow stronger and stronger with lowered temperature, until finally in martensite little if any carbide ever separates”. This is closely related to Robertson’s suggestion but focuses on the formation of carbide from the carbon not dissolved in the primarily formed ferrite. It seems that they had accepted Robertson’s suggestion of an increased solubility of carbon in ferrite at lower temperatures. Without paying any attention to the mechanism proposed by Robertson, Bhadeshia concluded that: “The evidence in their possession led them to suggest that the allotropic change occurs in advance of the carbide precipitation. In other words, the transformation is like martensite......To me this is an incredibly clever piece of deduction....”. This conclusion seems to be based on a misinterpretation of the work by Davenport and Bain who did not propose diffusionless growth of bainitic ferrite.

The use of TTT diagrams inspired numerous studies of the transformation of austenite in the following decade with reference to Davenport and Bain. Their picture of the mechanism was often accepted but without a detailed description. An exception was Wever and Lange who in 1932 presented an Fe-C phase diagram showing how an increased carbon solubility in ferrite finally reaches the composition of the parent austenite which makes a diffusionless transformation possible under local equilibrium conditions (8). It is interesting that they did not give reference to Robertson nor to Davenport and Bain. In general, the mechanism was simplified to say that bainitic ferrite forms martensitically. Finally, this simplification was accepted by Zener in his classical treatise on the mechanisms of austenite decomposition where he presumed that bainitic ferrite forms without carbon diffusion (9). Today his paper is the standard reference for the diffusionless hypothesis of bainite. Reference is sometimes given to Davenport and Bain but rarely to Robertson. In summary, Robertson may have been the first one to propose an increasing carbon content in bainitic ferrite with lowering temperature until the result is martensite. After being repeated by Davenport and Bain in a less clear way, it was not completely understood or simply forgotten and a simplified version based on diffusionless growth could spread without anybody really being responsible for that hypothesis. It does not seem right to put the responsibility on Davenport and Bain.

References

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