钢中微量元素的偏析与晶界脆化

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译者的话

《钢中微量元素的偏析与晶界脆化》一书是日本微量元素偏析分会于七十年代初期进行的一次范围广泛的文献调查文集。该文集主要是调查了美国和日本有关金属材料中微量元素偏析及晶界脆化的最新科学研究成果和实际生产、使用中存在的问题，其目的是便于开展和指导这方面的研究工作，提高金属材料的使用效果。文集内容包括了应用新实验技术研究表面问题的方法（场离子显微镜、电子显微镜分析和泡沫模型、离子探针等）、理论和机理研究工作的动向以及实际用钢存在的问题。所涉及的钢种有碳素钢、工具钢、超高强度钢、低合金钢、不锈钢及高温合金。文献调查者不仅汇总了现状，并有评述，进而提出了今后的研究方向。

钢与合金中微量元素偏析及晶界脆化，是关系到提高金属材料质量和充分发挥材料使用潜力的一个很重要的问题，是目前国内外金属材料工作者极为重视的问题之一。现在把这本文集介绍给大家，会有助于我们分析生产和使用中存在的问题，寻找解决问题的途径并进一步开展这方面的研究工作。

应当说明，正文的综述有的过于简要，这就需要继续查阅本文集介绍的大量的有关文献，才可以搞清楚问题的全貌。

本文集由王迪、邢文彬、解子章、徐志超、俞静、杨莲隐、郭方博等翻译。不当之处请读者批评指正。

目　录

文集前言

须藤　一

由日本钢铁学会、日本金属学会和日本学术振兴会三者所组成的钢铁基础共同研究会管理委员会，决定把钢中微量元素的偏析列为1970年以后的研究课题之一，为此设立了微量元素偏析分会。

无论是为了得到质量较高的金属材料，还是从节省资源和利用废料的观点出发，钢中微量元素的研究都是非常重要的问题。但由于微量元素的含量很少，同时存在状态很不均匀，材料试验的误差也较大，特别是在分析技术上还有些问题，所以还不能清楚地掌握钢中微量元素的作用。

近几年来，俄歇电子能谱分析装置（AES）和电子扫描分析装置（ESCA）等表面分析技术取得了很大的发展，使吸附和极薄层的研究工作得到了飞速的进展。因微量元素在晶界偏析所引起的钢铁材料的回火脆性，由于采用俄歇电子能谱仪进行分析，已从过去的假说阶段进入了实际证明的阶段。现在日本已经有了相当数量的俄歇电子能谱分析装置、电子扫描分析装置和离子扫描分析装置（IMMA），正在改变那种在回火脆性领域内的研究工作落后于美国的状态。本人认为，目前日本钢铁学会材料研究委员会的研究成果，虽然为数不多，也应当给以高度的评价。

在微量元素偏析分会所进行的有关微量元素偏析的研究工作中，应用俄歇电子能谱分析装置对回火脆性的研究已告一段落，但为了得出确切的结果，还有必要进行慎重的讨论，还要在这个问题上广泛征求各位研究工作者的不同意见。为了使研究工作不是一般地、泛泛地进行，就要集中研究的重点。有关晶界脆化的微量元素偏析问题可以作为研究的中心课题。不言而喻，结构钢的低温晶界裂纹、高温锻造和高温蠕变的晶界断裂、SR裂纹、

工具钢的500°F（260°C）脆性和沿晶界的热裂等等，都成为研究对象。为了使研究工作进行得比较深入，希望理论研究工作者也积极参加。近期将介绍各个领域中的研究报告，以资互相学习。这本文献调查报告文集汇总了这方面的资料（因经费关系仅仅刊载了主要内容），对于了解微量元素偏析和晶界脆化问题的全貌很有帮助。

1. 偏析问题的电子理论研究

堂山昌男

一、前　言

对于应用电子理论研究偏析问题的有关文献进行调查之后，现在深深感到这是一个内容相当广泛的问题。电子理论是个基本的手段，有很多问题的最终结果都可以用电子理论来处理。但也并不是所有问题都要最后归结到电子理论，有些问题可以在中途的各个阶段予以阐明。例如，作为统计热力学的方法，用结合强度的相互作用来表示原子间的相互作用，元素B固溶于母相A产生偏析时，AA 间结合强度为 E_{AA}，BB 间结合强度为 E_{BB}，AB 间结合强度为 E_{AB}，这是用统计热力学处理的方法。此外，认为微量元素的偏析状态与其在周期表中的位置有关等等，也是说明这种情况的例子之一。

存在偏析的情况下，必须首先确定所论及的偏析是多大尺寸范围的偏析。是宏观的钢锭上部与下部的偏析，还是边长小于1厘米的试样内的偏析；是电子显微镜可识别的偏析抑或是场离子显微镜可识别的偏析。钢锭如果产生了偏析，要区分是混合不好造成的偏析，还是凝固过程中出现的偏析。本文集不包括机械的非均匀混合、重力偏析以及凝固过程引起的偏析，而是研究在非常微小的视场下显示出来的偏析。

另外还必须区分是晶内偏析还是晶界偏析。例如GP区的形成等是晶内偏析。所谓一个合金相之内的偏析，又分为向晶界、位错或是点缺陷的偏析。总之，晶内偏析可以认为是微量元素或是合金元素的聚集。

关于偏析问题的电子理论，现在仍处于初始研究阶段。这里列举的文献不可能把这方面所有的内容都收集进来。

二、聚集理论

就聚集理论来说，过去分别用电子理论和弹性理论进行过研究，这本应是用电子理论解决的问题。所谓弹性理论，基本上是根据内层电子的相斥力和介于电子之间的金属离子间的吸引力而提出来的理论。

纯金属中的单一杂质可以通过模拟电位法来计算。但至今仍未在定量方面达到可信的程度。

就钢铁材料来说，因为铁本身属于过渡族金属，应用纯电子理论来处理还很困难。最初应用模拟电位法，但因自由电子极其近似，很难以处理。然而，近几年来模拟电位法已开始应用于过渡族贵金属方面。不过是用于处理传统上被牢固束缚的电子，有APW法、KKR法等电子理论方法，但还很少用于处理杂质原子及元素聚集。还有一种试验方法是屏蔽电势法。这种方法如果能很好使用，是否有可能应用于钢铁中的所有杂质元素呢？在这种情况下成问题的是杂质的有效电荷。杂质的有效电荷是由电场中的漫射测出的。

应用统计热力学的近似值研究原子间的相互作用和使用热力学数据研究中途的“轨迹修正”，在理论的实际应用上非常有效。

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一、模拟电位法、APW法、KKR法等

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四、不纯物原子与位错的相互作用

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六、电子散射与电阻

由于杂质原子的存在，传导电子产生散射现象。所以电阻测定是个可以很好地应用的方法。电阻测定的突出优点是能够精确地测量，既可以测定出整个试样的平均性能，又因为是个标量，所以信息量比向量少。对此，用道·汉斯—万·欧芬效应 (de Haas-van Alphen effect) 实验可以研究微小的散射过程。这还期待着今后的发展。

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