ULTRA-STEELS: INNOVATION OF STEEL STRUCTURES BY MATERIALS EVOLUTION

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ABSTRACT

To save natural resources and energy and conserve our planet healthy as well as to improve the quality-of-life, we need both breakthrough materials and new technologies to put the breakthrough materials together into a product or a steel structure. The Ultra-Steel project in NIMS/Japan has almost reached its goal as a fundamental research stage. “USC Plant” and “Steel Bridge” ideas are pursued from the viewpoint of the combined development of key materials technologies: materials fabrication in a plant scale, forming into a shape of the product, joining by new welding technique and high strength bolts, and surface design for excellent anti-oxidation property. For the future application, further collaborations become essential especially in accumulating various kinds of material data like fracture, fatigue, corrosion, and creep. International collaboration is the best way to perform everything efficiently.

KEYWORDS

Eco-development; microstructural design; strength; life; heat resistant steel; building steel; welding; joining; surface oxidation.

INTRODUCTION

Ultra-Steel project was launched nine years ago in 1997. In the first five years, several types of ultra-steels with “doubled strength” or “doubled life” were developed along with marked development in related technologies. In the second term, “doubled strength in service and more than doubled life of structure” have been pursued with attempts to apply them into the specific future steel structures. These attempts are being driven successfully under good collaboration with end-user sides (Fig.1).

For better eco-development, demands for highly advanced steels have become stronger in the industrialized nations. At the same time new economic centers have already taken active parts in the world off in our prediction. On a superficial level it seems that one part of the world paves the new way to reduce the consumption of steels and another part wants to increase the production of steels beyond the past level in the 20th century. But the author believes all the steel people hope to build up the sustainable planet with advanced steel technologies. The Ultra-Steel concept is so basic that it can be widely applied internationally from now on.

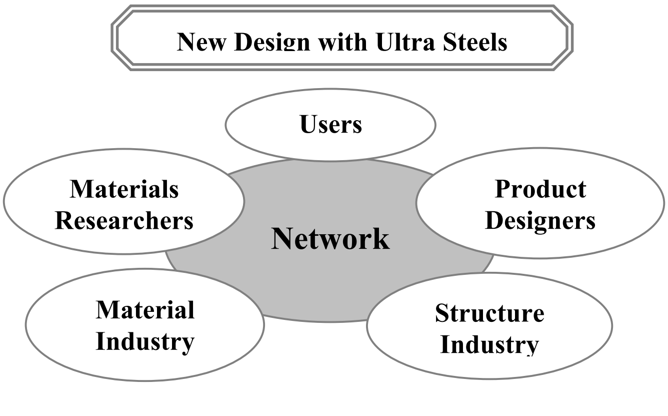

Fig.1 Network is the key to put new idea to practical use.

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1. SIGNIFICANCE OF ULTRA-STEEL CONCEPT

"Not incremental but breakthrough" target for new innovative era

Steels have already reached a high level in performance and widely mass-produced. The end-users have already no idea to accept further incremental improvement in material properties. Even an inch progress or a bit change in material property always requires related modification in every step in fabricating a final product. The end-users need an extra investment to follow the incremental improvement of material property. Can they successfully pay out it after a short period? It has become harder and harder for them to make a great success through the material change.

The end-users have liked a kind of standard materials more than new ones. Accordingly material providers have tried to supply the standard materials at lower cost or with better properties than their competitors. As far as there existed a margin to improve through already established technology, this system has worked and made a continuous progress with a small step in property as shown in Fig.2. The incremental improvement is also able to double the property by accumulation for years.

Once the margin is closely eaten up, the progress will become levelled off and very much sluggish. On the other hand, the end-users will steadily demand the progress in the material properties so that they can sell better products to their customers. When the improvement becomes too small to afford the modification in the following fabrication processes, the end-users cease to require the surplus specification and in turn begin to seek lower price and modification in materials for easier fabrication. Cut the production cost! If the customer demands a higher performance, they will try to answer it bay altering the product design still using the same materials. Anyway they have to invest some money into some fields all the time.

Now the time is coming when the end-users again will look for new materials with breakthrough properties. But for the time being, very marked improvement enough to totally change the fabrication processes of product will be targeted. What is the minimum requirement in the jump for property? The answer could be "at least +100%". Thus, "***double strength***" and "***double life***" were set as main targets prior to the start of the Ultra-steel project.

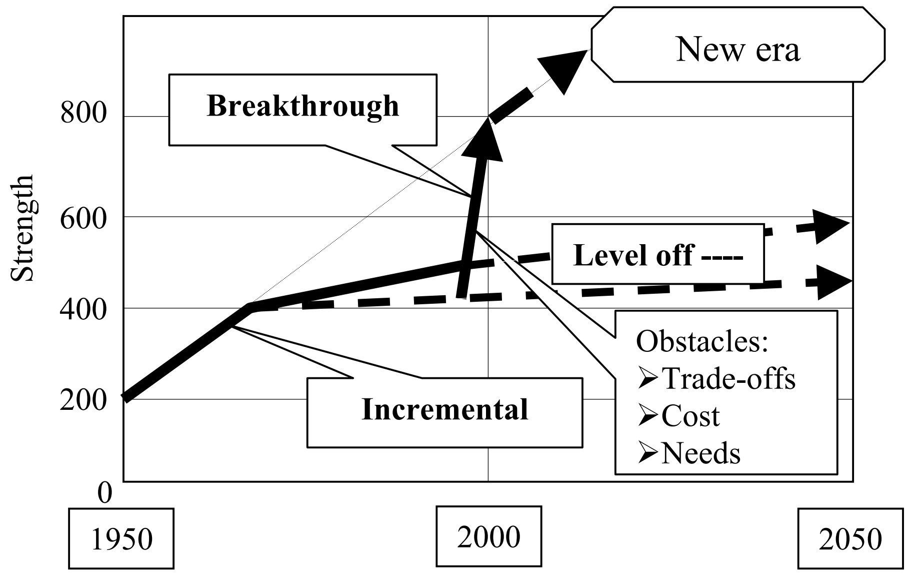

Fig.2 Breakthrough is requested for new innovative era.

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Better trade-offs for better eco-development

Basically the purpose of materials design has been to enhance the value in use of the materials, or physical, chemical, mechanical properties and so on, which can be utilized to develop the frontier of human activities. And this measure, ***Frontier Performance of Materials***, should continue to be essential from now on out.

Increased human activities involved in the development have become influentially huge compared with the disposal capacity of the earth to threaten the soundness of our planet. Usually the higher the frontier performance of materials is concerned; the more the environmental burden is accompanied; in other words they are a trade-off. Accordingly a measure to evaluate ***Environment Performance of Materials*** is strongly necessitated to make better balance of the trade-off.

Pursuing only the frontier performance of materials has one more problem. Stressing the significance of products over the detrimental effects on human and environment has sometimes ignored the toxicity of substances in the materials. How comfortable the human products are for human itself is also important. If there is the serious incompatibility between human and human products, human cannot survive healthy in the human-made world. Hence, ***Amenity Performance of Materials*** is also one of the essentials in considering the future materials.

Based upon the consideration of future needs for materials, the ***Ecomaterials*** concept has been proposed with a special emphasis to appeal the **ENVIRONMENT-CONSCIOUS-MATERIALS** with better balance among three independent measures (Fig.3).

In the conventional alloy design, the optimized compositions of alloying elements for given microstructure has been our major concern for better enhancement of materials properties like strength, toughness, corrosion resistance etc. However, for easy recycling, simpler combinations of safe and ample elements are favoured. This means we need novel approaches for materials design with less aid of alloying elements. For fulfilling the customer demands, the end-users needs the materials like high strength and high ductility. However, this requirement is also a trade-off.

To get rid of these restrains or acquire better trade-offs, a new concept for material design has been proposed; namely the microstructural design of performance especially by aid of multi-phase or complex geometrical design. “Never alter the chemical compositions and improve the material performance” is now the key in “Eco-metallurgy” and also one of the essential ideas of “Ultra-steel”.

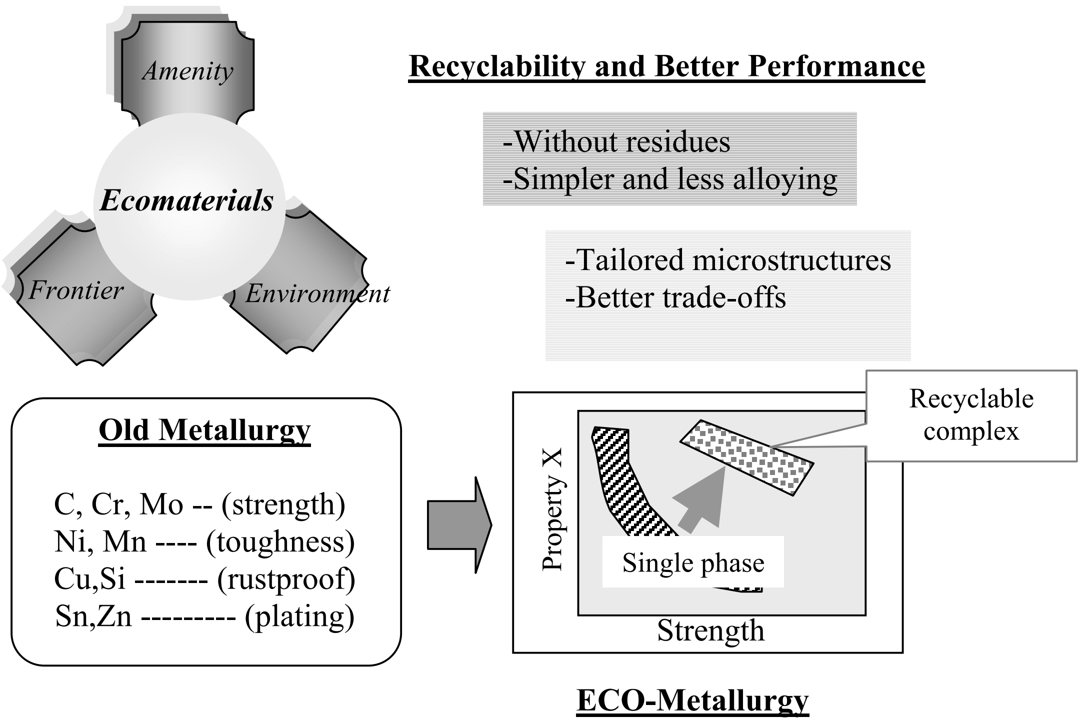

Fig.3 Paradigm shift is pursued in material design for eco-development.

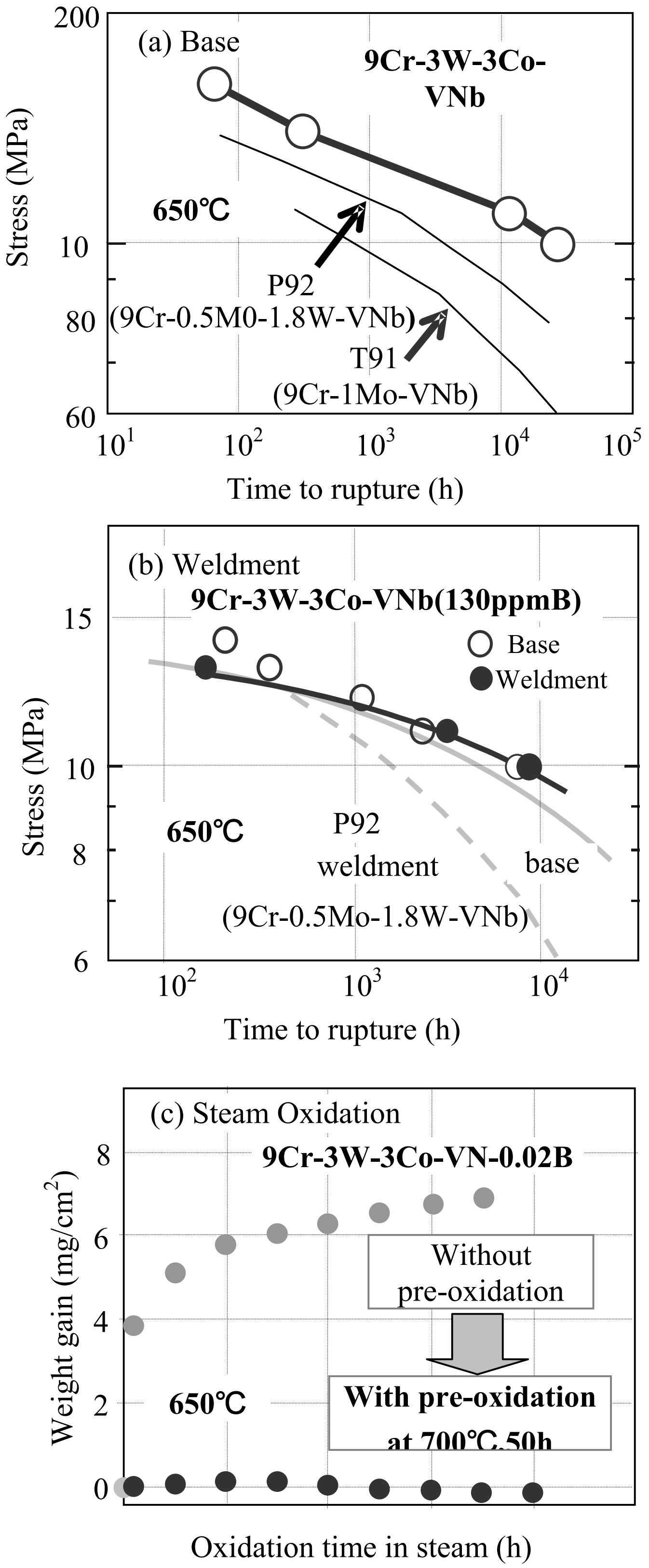

Fig.4 Remarked improvements in high temperature properties have been accomplished for base metal strength, weldment creep, and steam oxidation resistance.

How can "Material Use in High-Temperature" be materialized?

Towards realization of ultra-supercritical steam boiler, based on the material design which stabilizes the microstructures near the grain boundary for a long time, while achieving creation of a large thickness pipe like as the main steamy pipe etc., control of the type IV creep crack by the formation of the thin welding HAZ width, and the improvement of oxidation-resistance in the high temperature steam by the surface protection film, a new structure with heat-resistant steel are attained.

In the long-term service, the strength drop in the base steel sometimes happened to be larger than predicted, and threatened the safe operation seriously. Hence the ***long-term stability*** of the creep strength is the most important issue in developing new heat-resistant steel. We have challenged to make the operation temperature higher up to 650°C with guaranteeing the long-term stability. Fig.4 (a) shows one of our attempts to improve the high temperature creep drastically by the addition of B.

In welded structures, a kind of internal cracking takes place in the HAZ, called by ***Type-IV crack***. The initiation mechanism has not yet been fully clarified, so we have intended to decrease the initiation chance as much as possible. Eighty percent creep strength compared to that of the matrix is high enough in the engineering viewpoint. The addition of B brings about the excellent creep performance for the weldment as good as that for the base metal as indicated in Fig.4 (b)

At higher operation temperature, not only the matrix but also the surface is exposed under the sever condition. The steel surface becomes very vulnerable to ***steam oxidation*** at higher temperature. However, we have attempted to suppress it by an economical way. Fig.4 (c) appeals the effectiveness of pre-oxidation in the suppression of steam oxidation.

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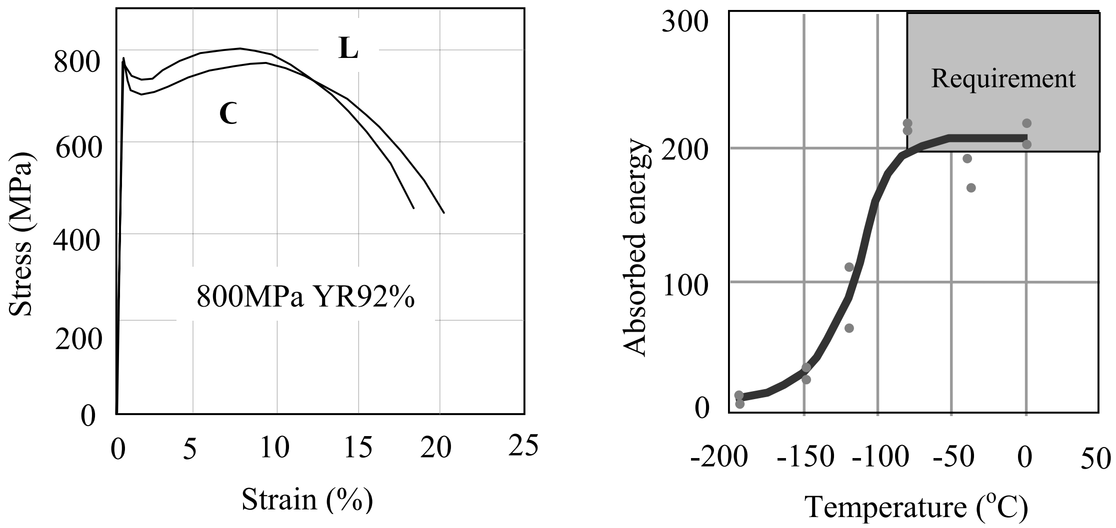
How can “High-Strength in Steel Structures” be materialized?

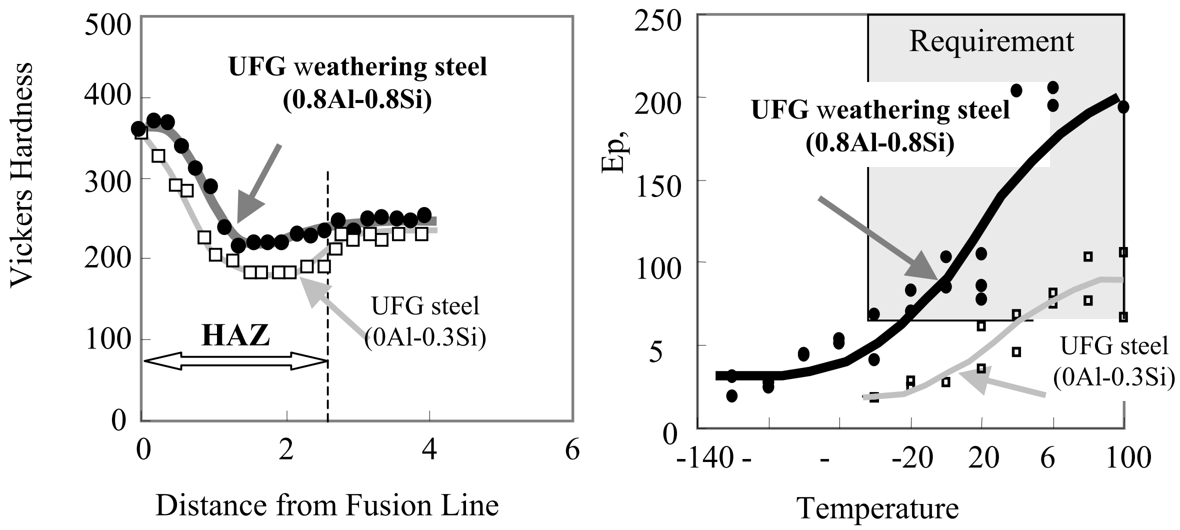
By developing refinement technology, we aim at ‘factor 4’ ultra-steel with both high strength and corrosion-resistant in thick plate size, and design and investigate a structure model of the new steel joined by ultra-narrow gap GMA welding, high power pulse CO_2 laser welding, and the 2000MPa-class bolt. 0 1000 2000 3000 4000 5000

Conventional weathering steels contain Cu or Ni and we use Zn or Sn as plating. From the viewpoint of ***easy recycling***, these “tramp elements” or residues are not favourable. We have explored an alternative alloying and found the combined addition of 0.8wt%Si and 0.8wt%Al feasible in terms of the formation of stable oxide at surface as well as the ingot making. However, both are embrittling elements in steel. With the conventional grain size, the steel is brittle at room temperature. Hence, the ultra-fine grained (UFG) steel of 0.8Al-0.8Si was made, which demonstrates both high strength and excellent Charpy impact property as seen in Fig.5 (a).

The designers of steel structures are very much concerned about the ***reliability of welded joints***: especially the softening of HAZ in high strength steels and the joint toughness. Fig.5 (b) shows the enhanced HAZ hardness and Charpy impact property for the ultra-fine grained 0.8Al-0.8Si steel compared with the conventional UFG weldable steel. Surprisingly the requirement for joint toughness is for the first time cleared with these chemical compositions.



(a) Strength and toughness of UFG base metal (0.8Al-0.8Si)



(b) Hardness and toughness of welded joint of UFG 0.8Al-0.8Si steel

Fig.5 Proposal of a weldable, high strength, and high toughness weathering steel

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3. INTERNATIONAL COLLABORATION FOR GLOBAL SUSTAINABILITY

Developing countries want more energy and raw materials in order to make the quality of their lives as good as in industrialized countries. China had the steel production of about 100 million tons in 1990s and will predict that of over 300 million tons in 2005. Now the total product in the world surpassed one billion tons in 2004, which was 300 million tons more or 40% more compared with that in 1990. This simply means that the natural resource life is shortened with a 40% faster rate. And apparently the market prices of raw metals have jumped up and been more than doubled. Thus the sustainability of our planet is being highly threatened. To share the future of the earth by all people advanced and sustainable technologies are substantially longed for in the developing countries (Fig.6). The application of similar level technologies as in industrialized countries is quite foolish, since it merely brings about the same stories in many nations as repeated copies of the 20th century type of technologies. I believe the Ultra-steel is a typical example of the 21st century type technologies.

We need to share the basic understandings on the advanced structural steels for the world-wide use. Among all the data accumulation of the time-dependent properties should be minded, since it takes long time and the time-dependent properties are closely related to the safe and reliable usage of steel structures. Organizing an international round table is one of the urgent demands to initiate the international collaboration.

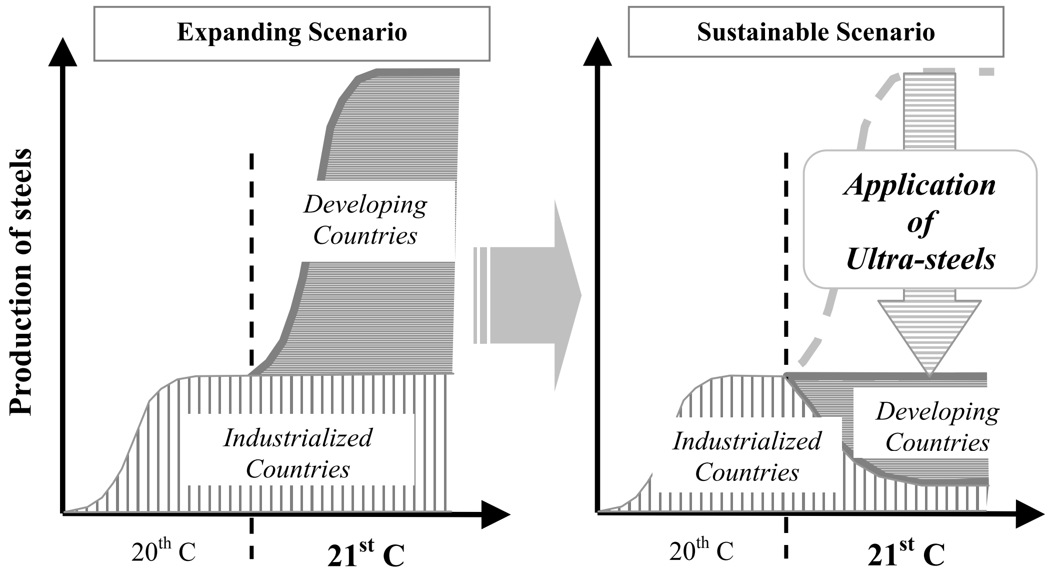

Fig.6 Two scenarios as opposite end for our future

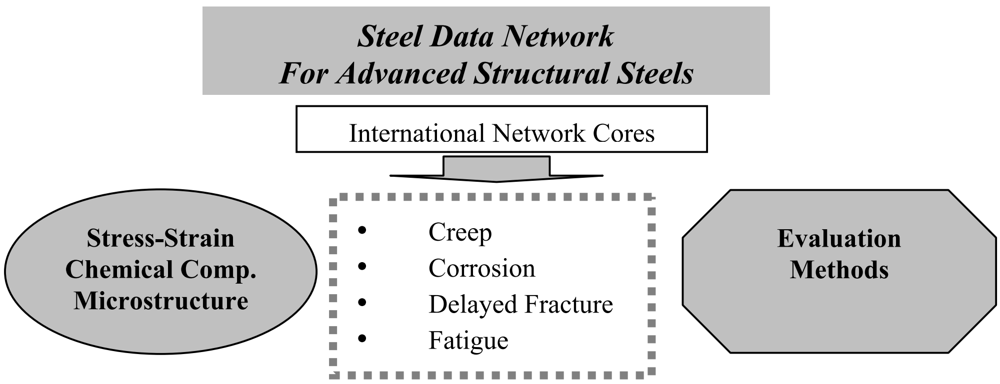

Fig.7 Proposal of "Steel Data Network for Advanced Structural Steels"

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