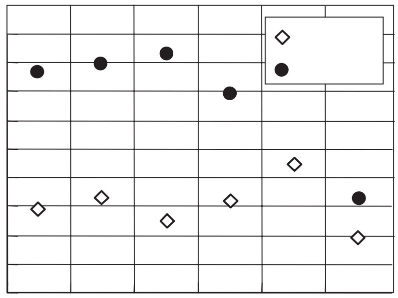
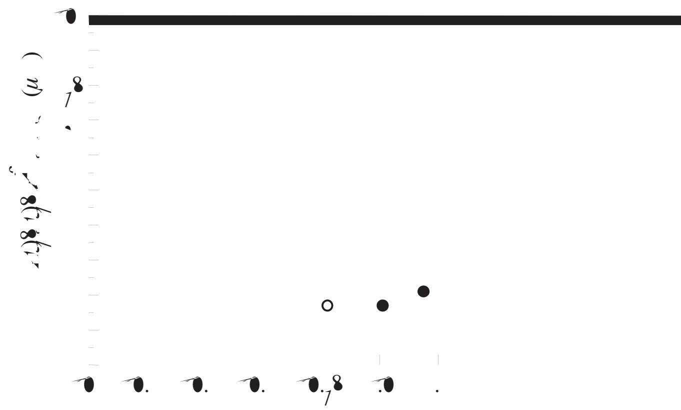
Abstract:





results showing that reduction of stress concentration per unit of area and reduction of the concentration of impurities at grain boundaries by grain refinement increase grain boundary (intergranular) strength[4]. In other words, intergranular fracture can be suppressed by grain refinement.

In automobile suspension and drive train parts, the portions which are subjected to the highest loads are strengthened by performing quenching and loads tempering (hereinafter, QT) treatment. Much research on refinement of the ferrite grains[5] of the base material has been done in the past with the aim of achieving high strength and high toughness. However, when using QT materials, refinement of the prior γ grains in the quenched portion, and not refinement of ferrite grains in the base material, is critical for application to suspension and drive train parts.

3. Microstructure Refinement Techniques

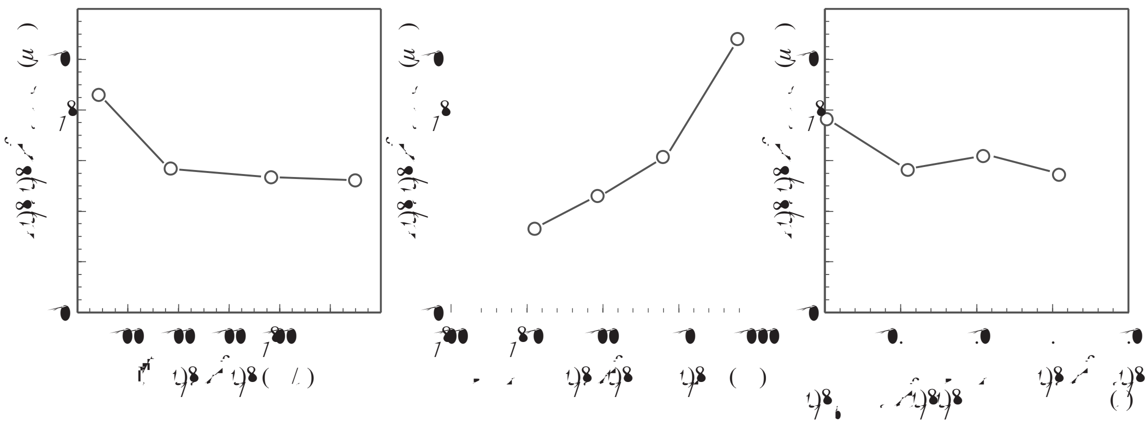
3.1 Study of Elements

In order to identify elements which are effective for refining prior γ grains, steel ingots for research purpose were prepared by adding various elements to JIS S48C (JIS: Japanese Industrial Standards) steel as the base steel as test materials for induction quenching experiments. Addition was set at the amount of each element which bonds with a constant amount of carbon. To eliminate the effect of the prior microstructure, specimens were heated to 1 000°C and quenched in the first stage, followed by induction quenching in the second stage at specified heating temperatures. Prior γ grains in the quenched portion were measured by an intercept method. In all cases, the prior γ grains were revealed using a dedicated etchant (Gamma R etchant) [6,7] which was developed by the authors for use in revealing ultrafine γ grain boundaries. As shown in **Fig. 2**, Mo was found to have the largest prior γ grain refining effect among the elements studied. Next, induction quenched specimens were prepared in the same manner, using ingots with various Mo contents up to 1.2%. Induction quenching was performed at 1 000°C in the first pass and 900°C in the second pass, and the prior γ grain size of the quenched portion was measured. The results are shown in **Fig. 3**. The grain refinement effect was substantially saturated at Mo addition of 0.4 mass% or more.

3.2 Study of Induction Heating Conditions

The effect of induction quenching conditions was studied using 0.4 mass% Mo steel. As induction quenching conditions, experiments were performed at heating rates from 40 to 1 000°C/s, maximum heating temperatures from 850 to 1 000°C, and time from heating to quenching in water varied between 0 and 1.5 s.

As shown in **Fig. 4**, within the range of conditions in these experiments, the effects of the heating rate and the time from heating to quenching on the prior γ grain size were small, and the results were basically determined by



the maximum heating temperature.

4. Pursuit of Grain Refinement

In the following, “developed steel” refers to steel with refined prior γ grain microstructure obtained by a combination of Mo addition and low temperature induction heating. The chemical composition of the developed steel is shown in **Table 1**. For comparison purposes, a JIS S53C equivalent steel (hereinafter, S53C) was used. The developed steel was produced using ingots for research purpose by hot forging to 60 mm in diameter after holding at 1 200°C × 1h, followed by normalizing in air at 850°C × 1 h. The comparison steel, S53C, was a standard mass-production material produced by commercial steelmaking and rolling processes. Micro tensile test pieces were taken from the axial direction (L direc-

displayed a surface fracture origin. Moreover, in the interaction with carbon as the effect of the solid solution Mo. Although Mo interacts with C in austenite, its bonding force is smaller than that of strong carbide forming elements such as Ti, Nb, etc. Because this Mo addition makes the largest contribution to grain refinement, it is considered that grain grown during short-time heating, like that in induction quenching, contributes through sq [illegible]

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