I. Introduction.

The definition of forgeability is complicated and is not definite. However, for comparison in forgeability, variations in the material used must be seen. While there may be several methods thereof, we first of all measured simple resistance to deformation. It is necessary to fully note that the resistance to deformation remarkably varies with the speed of deformation. On the other hand, it is also considered that forgeability varies with the methods of forging. Therefore, in discussing forgeability, it must be predetermined what are to be made the objects for comparison and what forging method is to be used. Taking these points into consideration, we selected to use a material consisting of 2% Cu, 1.5% Mg and 8% Zn, the remainder being Al. We investigated the difference in forgeability of this material between as cast and as forged and annealed and also the relation between forgeability and recrystallization of such forged material after heat-treatment. Then we investigated the relation between forgeability and addition of Mn or Cr as an agent for preventing season cracking. We thus would like to report the following results.

II. Methods of Preparing and Testing Specimens.

The specimens were cylindrical, being 18 to 20 mm in diameter and 20 to 25 mm high. For specimens of the cast material, some round rod-shaped material pieces 25 mm in diameter were cut into pieces 20 mm in diameter and 25 mm high. The others were finished into round rods 20 mm in diameter by being hot forged and thence were finished into test pieces 18 mm in diameter and 20 mm high. They were made specimens after being annealed at 350°C for 6 hours. The compositions of the specimens used in our experiments were as shown in Table 1. The results of analysis of some of these specimens coincided well with the mixed compositions. Therefore, we did not analyze the others. As we intended to operate a forging machine statically, we used a variable-speed Amsler type testing machine and carried on the experiments by varying the speed range from 5 to 100 mm/min.

III. Results of Experiments.

(1) Cast Material

The relation between the forging pressure and the

<table>
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<th>No.</th>
<th>Cu %</th>
<th>Mg %</th>
<th>Zn %</th>
<th>Mn %</th>
<th>Cr %</th>
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<td>---</td>
<td>---</td>
<td>1.0</td>
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</tr>
</tbody>
</table>

* Tokyo Institute of Technology
** Hokuriku Keikinzoku K. K.
The results in Figure 1 are with the composition of No. 11 of Table I unless otherwise specified. As seen from these curves, the higher the forging temperature, the lower the yielding point and the better the forgeability.

The resistance to deformation and the amount of deformation as approximately calculated from those curves and correlated with the forging temperatures are as shown in Figure 2.

The relation between forging speed and the amount of deformation is approximately the same way, gradually lowering until the temperature reaches 250°C, very remarkably lowering when the temperature is over 300°C and tending again to gradually lower when the temperature is over 350°C. In accordance with the variations of the resistance to deformation and of the yielding point, which show the degree of forgeability, the amount of deformation increases in proportion to the rise of the forging temperature, remarkably until the temperature reaches 350°C but tending to increase comparatively gradually over that temperature. The relation between the forging speed and the amount of deformation and that between the resistance to deformation and the yielding point are as shown in Figure 3. The amount of deformation reaches its maximum value in the vicinity of 20mm/min., but decreases when in the forging speed over that is reached. The resistance amount of deformation and rapidly decreases until the forging speed of 20mm/min. is reached but again increases after the minimum point is passed.

The variation of the yield point shows approximately similar tendency but its drop is remarkably slow until the minimum point is reached and its rise is rapid when the forging speed is higher than 30mm/min. These various characters are of course correlated with one another and show some limits to the forging speed for these alloys. The safety limits to the forging temperature are in the range of 350 to 430°C and the results shown in Figure 3 were also obtained within this temperature range.

(2) Forged and Annealed Material.

The relation between the forging pressure and the decrease of the height of the test specimen when the specimen was forged at the respective temperatures while the forging speed was kept constant at 5mm/min. or was varied and after it was held at the respective temperatures for 1/2 hour is as shown in Figure 1.

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(2) Forged and Annealed Material.

The relation between the forging pressure and the decrease of the height of the test specimen when the specimen was forged at the respective temperatures while the forging speed was kept constant at 20mm/min. in the height of the results of the cast material and after it was held at the respective temperatures for 1/2 hour is as shown in Figure 4, as very different from the tendency of the curves of Figure 1 and showing that the relation is evidently influenced by the derivation of the forged material.

The curve of the part over the yield point is accompanied by the decrease of the height as the temperature rises, and the higher the forging temperature, the more remarkable is such tendency. Thus it may be said that forgeability is improved though qualitatively. The relation similar to that in Figure 2 is as shown in Figure 5. The resistance to deformation further rapidly decreases when the temperature becomes higher than about 200°C. The yield point further lowers when the temperature is over 350°C. The resistance decreases and the yield point lowers further rapidly when the temperature becomes higher than about 300°C. The amount of deformation shows rapid increase until the temperature reaches 300°C but demonstrates a little slower increase when the temperature is over 300°C. The safe amount of deformation shows the maximum point around 400°C as in the case of the cast specimen. While the forging speed does not coincide with that of the cast material, the resistance to deformation and the yield point are remarkably lower than those of the cast material but the amount of deformation increases on the contrary, thus well coinciding with the qualitative results in Figure 4. That is to say, the increase of forgeability of the forged and annealed ma-
hedral as compared by these results. The forgeability of the forged and annealed material and that of the cast material can be clearly seen in the relation between the forging speed and the height. When the forging speed of the cast material exceeds certain limits, the forgeability is evident, for example, as in curves 7 and 8 in Figure 1. The amplitude of the slip phenomenon as seen in the vicinity of the yield point of soft steel increases in proportion to the forging speed in the cast material but does not appear in the forged and annealed material. Metallographically speaking, the diffusion of the cored structure proceeds continuously until the forging temperature is reached. When the forging temperature is close to the solubility limit, the dispersion of the precipitate proceeds simultaneously but the speed of the dispersion is not always the same. On the other hand, when the material of such uneven structure is subjected to forging pressure, every part of the structure must be deformed similarly. Therefore, the pressure must be shared by each part of the structure. However, where there exist compounds hard to be worked, there will naturally exist partial limits to the forging temperature. Thus it is considered that while below a certain forging speed, forging is comparatively easy, over such limit, it becomes difficult. Cracks are caused and discontinuous curves similar to the so-called slip phenomena appear. On the contrary, in the forged and annealed material, no slip phenomenon appears even when the forging speed is high, because the material has been made uniform and compounds hard to work have been fine-grained and dispersed by pre-treatment, forging being thus facilitated, as distinctive from the structure.

(3) Relation Between Forgeability and Mn or Cr.

When the specimen was heated at 420°C for an hour and was forged at the speed of 20 mm/min., the resistance to deformation, the yield point and the amount of deformation were found, the results being as shown in Figure 6. Speaking of the effect of Mn first of all, with the increase of the amount of Mn added, the resistance to deformation increases and the yield point becomes higher rapidly when Mn content is over about 0.8%, while the amount of deformation decreases, being considerably influenced by the addition of about 0.2% and little influenced by the addition up to 0.5%, and rapidly decreases with Mn content over that. The function of Cr is not so remarkable as that of Mn. The resistance to deformation tends to increase a little in accordance with the increase of Cr content. The rise of the yield point is great as compared with change of the resistance to deformation but is small as compared with the influence of Mn. The amount of deformation decreases a little in proportion to the amount of Cr added and changes little within the range of 0.1 to 0.6% above which the effect of Cr begins to appear. Then, when the content of Mn is kept constant at 0.5% and the amount of Cr is changed, the increase of the resistance to deformation and the rise of the yield point are generally greater than in the case of adding Cr alone and the amount of deformation decreases but the effect of the amount of addition of Cr on the change of various characters is not so different from the results of the case when Mn is not added. When the content of Cr is kept constant at 0.2% and the amount of Mn is increased, the increase of the resistance to deformation, the rise of the yield point and the decrease of the amount of deformation tend to become rather slower as compared with the case when Mn alone is added and increased. Thus, it can be said that, the simultaneous addition of Mn and Cr does not give any remarkable effect on forgeability as compared with the case where they are added individually. In the sight of the change of structure, we find that No. 1 seems to have almost completed recrystallization at the time of forging and that No. 2 to which Cu has been added becomes difficult to recrystallize but shows a flat crystal which seems to extend at right angles to the direction of forging, having thus already caused recrystallization though
incompletely. When Cr is further added, the recrystallization becomes hard to occur. When 0.5 to 0.8% Mn is added, further remarkable preventive action can be seen and as a result recrystallization at the time of forging is almost hard to occur. The Al-Cr compound which appears in case the amount of Cr is increased is not deformed by forging but remains as it is, as remarkably different from other compounds of this kind of alloy.

(4) Recrystallization after Heat-treatment

In general, Al or D2 is not recrystallized when heated below the forging temperature but is recrystallized when heated at a temperature over the forging temperature.

When the specimens which have been forged at respective temperatures, heated for an hour at 450°C and quenched are microscopically inspected, it is found that the relation between the recrystallization at the time of forging and the recrystallizing phenomenon due to subsequent heat-treatments in this kind of alloy is exactly the same as in the cast of D2. The specimen when forged below the solution heat-treatment temperature tends to coarsen, to the larger extent as the forging temperature approaches the solution heat-treatment temperature. When microscopically inspected, it is found that the recrystallization structure is entirely independent of the forging direction at the forging temperature below 200°C. When the specimen is forged above 300°C at which the recrystallization at the time of forging starts, the crystal grain field becomes irregular and a layer structure extending at right angles to the forging direction is obtained. When forged at a temperature above the solution heat-treatment temperature, the structure very little changes. When forged while the temperature is kept constant at 420°C, specimens No. 1 and 2 which do not contain Mn and Cr do not show the fibrous structure but show the recrystallized structure which is remarkably coarsened because the forging temperature is close to the solution temperature. It is seen that, with the addition of Mn and Cr in the order of 0.5 and 0.3%, respectively, the microstructure shows a considerable effect.

IV. Conclusion.

The above results are concluded as follows:

(1) In case the cast material is forged at a high temperature, the decrease of the resistance to deformation and the rise of the yield point are rapid within the temperature range of 300 to 350°C. The forgeability remarkably improves at a temperature above 350°C The forging temperature for safe deformation is within the range of 350 to 450°C.

(2) The case of the forged and annealed material is similar to the case of the cast material. The point where the resistance to deformation and other characters rapidly change to are at lower temperature sand, while the resistance to deformation decreases and the yield point lowers, the amount of deformation increases. However, the range of temperatures for safe deformation is exactly the same as that of case (1)

(3) When Mn or Cr is added to the contents of the specimen, the resistance to deformation and others increase in proportion to the added amount. However, the effect of Cr is much smaller than that of Mn. Even in case both are added there to, it may be considered that the effect of each of them appears.

(4) The forging speed has a critical point where the effect of the forging speed clearly appears and when a slip phenomenon is seen in the curve showing the decrease of the height against the forging pressure this phenomenon is considered to accompany the generation and progress of cracks.

(5) When the specimen is heat-treated after it is forged, the structure which is not recrystallized at the time of forging is recrystallized independently of the forging direction but the structure which is recrystallized at the time of forging retains the fibrous structure at the time of forging as it is and the crystal grows in the form of a layer. The closer the forging temperature is to the solution heat-treatment temperature, the coarser is the crystal. However, when the specimen is forged at a temperature above the solution heat-treatment temperature, the structure does not change. The effects of Mn and Cr in such heat-treatment are remarkably stabilizing the fibrous structure in recrystallization and preventing the growth of the crystal grains.