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Investigations on Cold Die Forging of a Gear Utilizing Divided Flow*

(1st Report, Examination of applicable condition for a spur gear)

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This investigation intends to obtain the basic data for applying a newly proposed process utilizing a divided flow to actual gear-toothed machine parts. In this first report, a two step forging method is used for the working of a spur gear and the possibility of cold precision die forging for the gear is examined experimentally, when a preliminary closed die forging is combined with the process utilizing the divided flow. In this experiment, the process has been successful in the complete filling up of materials into a die cavity under a low working pressure and is found applicable to various initial thicknesses of materials. Suitable restriction of a centripetal material flow, is found more effective for decreasing the working pressure and saving the material.

Key Words : Cold Precision Forging, Divided Flow, Relief-Hole Principle, Low Working Pressure, Complete Filling Up, Spur Gear

1. Introduction

In a die forging, the process of complete filling up of materials into a die cavity is regarded most important for improving the dimensional accuracy of forged products. Complete filling up only by the conventional closed die forging causes a fractional reduction in area of materials to reach 1.0 at the stroke end. This requires an infinitely large working load as a matter of course theoretically and it makes the complete filling up impossible.[1] If the working load required for complete filling up can be reduced considerably by any special device, dimensional accuracy of the forged products will be improved remarkably and availability of the die forging will increase much more.

Recently one of the authors has succeeded in realizing a precision die forging of a "spur gear with boss", which has the same dimensional accuracy as that of a cut spur gear, by means of simultaneous working of the portion of the tooth form as well as that of the boss.[2]

The reason for the success can be explained as follows. In the working step of such a gear, the material flow is somehow divided into an inward flow and an outward one. These divided flows control an increase of the fractional reduction in area and that of the working load, and it reduces the pressure on the tools used. In this way, the complete filling up is considered possible. That is, it is very important to keep up the fractional reduction in area always smaller than 1.0 even when the filling up of the portion of tooth form is realized completely.

If the above-mentioned fact is true, the process utilizing the divided flow must be duly appreciated for the purpose of improving the dimensional accuracy of forged products, because realizing the divided flow is considered possible in various other cases besides the above.

In this investigation, a two step forging method is applied to a cold die forging of gears and its availability is examined experimentally, where this method is presented newly by the authors for the purpose of realizing the divided flow which is effective to reduction of the working load. Fundamental examinations of the process utilizing the divided flow have been already treated in other reports.[3]~[6] Especially, this investigation intends to obtain the basic data for applying the newly proposed process to actual gear-toothed machine parts.

2. Working Principle and its Fundamental Considerations

The flow relief-axis principle is used widely as a means for decreasing the working load.[7] In this principle, a flow port is provided in the central portion of a flat die and an axis is formed artificially on the material worked. This extruded axis is removed from the product after the working. This axis always gives the material a flow relief port. So, the raising of the fractional reduction in area mentioned above is suppressed and the steep increase of pressure known as a friction hill is also suppressed, that is, this principle can be considered a useful method for decreasing the working load and also an effective means for realizing the divided flow mentioned above. Nevertheless, there is no report which suggestes the positive application to improving the dimensional accuracy of forged products.

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In addition to the above principle, the authors present a new method on another principle as a means for more easily realizing the divided flow, which might be called "a flow relief-hole principle".(6) In this principle, a flow relief port is provided in the central portion of a material on the contrary to the above. A material can flow into the relief-hole and the divided flow can be realized easily.

For the purpose of clarifying the basic features of the process utilizing the divided flow, the filling up of a barrelled disk specimen into the die corner was taken up as the basic model and was examined not only theoretically but also experimentally with the following conclusions.(3)(4)

When the process on the relief-hole principle is used, for instance the relief-hole shrinks with a depression added and finally it is closed up completely. The working has to be finished before its complete closure. But, the applicable working condition is found to be comparatively limited.

A two step forging method was proposed anew for delaying the hole closure and for enlarging the applicable condition.(5) In this method, a preliminary closed die forging is done in the first step at a low working pressure which is allowed for the tool strength and the process on the relief-hole principle follows in the second step. Combination of these two steps accomplishes the complete filling up. The applicable range of the process utilizing the divided flow could be enlarged by this method.

Next, the difference of the principle using the relief-axis from that using the relief-hole was examined. In the relief-axis principle, the flow resistance to the axis extrusion rose with an increase of the fractional force on the axis portion but did not change so much. In the relief-hole principle, the flow resistance to the shrinkage of the hole diameter rose positively and expanded the outward material flow component required for the filling up into the die corner, and this feature renders the relief-hole principle more effective than the relief-axis one for decreasing the filling up pressure.

Moreover, even if the relief-hole principle is used in the second step of the two step forging method, the increase of the resistance to the shrinkage of hole is not always suitable for that of the resistance to the filling up into the die corner. A flow restriction method is also proposed in the use of the relief-hole principle.(6) In this method, a mandrel is inserted artificially into the relief-hole and the resistance towards the inside is raised positively. Thus, the applicable range of the process utilizing the divided flow can be much widened by this method.

In this report, the process utilizing the divided flow is used for the working of a spur gear and the possibility of cold precision die forging of the gear is examined on the basis of the above mentioned considerations.

Especially, in forming a spur gear, an initial diameter of specimens is equal to a dedendum circular one of the gear adopted and much more of the outward material flow is required for the complete filling up into the die tooth cavity. Therefore, it is important how to apply a preliminary closed die forging in the first step.

3. Experimental Conditions

The dimensions of the adopted spur gear are shown in Table 1. The test specimen is a commercially pure aluminium with 19.5 mm in the diameter, which is the same as in the case of the dedendum circle of the gear, and is annealed at 420°c for 60 minutes. The mechanical properties are shown in Table 2.

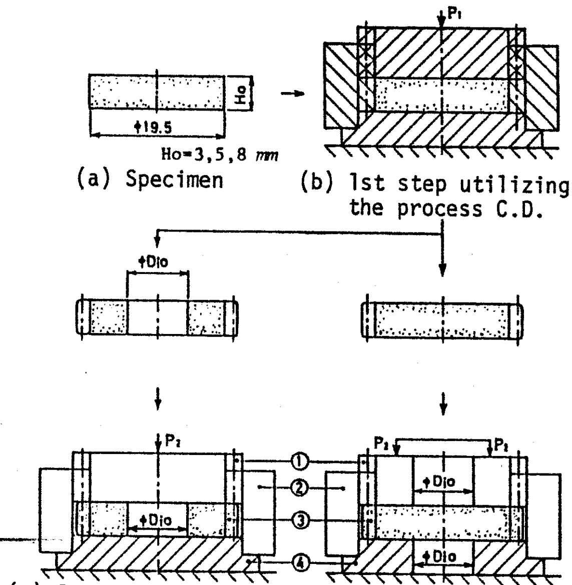
The adopted working method is a two step forging method shown in Fig.1. The first step is the conventional closed die forging C.D. and the specimen is depressed stepwise by increasing the working load P_1

Table 1 Dimensions of the adopted involute spur gear

Number of teeth	22
Module	1.0
Pressure angle	20°
Addendum modification coefficient	0
Tooth profile	Standard full depth tooth

Table 2 Mechanical properties of the specimens

Specimen	Thickness Ho *mm*	$\sigma=F\varepsilon^n$ F *MPa*	$\sigma=F\varepsilon^n$ n	H_v (100)
A1100-0	3.0	178	0.29	24.2
A1100-0	5.0	151	0.28	23.9
A1050-0	8.0	135	0.31	20.3



(c) 2nd step utilizing the process R.H. (d) 2nd step utilizing the process R.A.

① :Upper punch ② :Carved container
③ :Half-worked specimen ④ :Lower platen

Fig.1 Two step forging method and its procedure
(where the process C.D. means the conventional closed die forging and the processes R.H. and R.A. are those utilizing the principles of flow relief-hole and flow relief-axis respectively)

3*9.8 kN at a time.

The second step is the process utilizing the divided flow. When the flow relief-hole principle R.H. is used after the process C.D., a relief-hole is bored in the half-worked specimen by drilling and it is compressed again in the same die. When the flow relief-axis principle R.A. is used after the process C.D., the half-worked specimen is compressed again in the die with the relief-axis in the center of the punch. The initial diameters of the relief-hole and the relief-axis are changed to various sizes and these are denoted with D_{io} hereafter. The specimen is depressed stepwise by increasing the working load P_2 2*9.8 kN at a time and the filling up of materials into the die tooth cavity is observed carefully.

The state is defined here as the completely filled up state, when flashes (that can be felt with one's finger) come to appear on the outermost sides of all the products.

The working load P_2 in this state and its mean working pressure $\bar{p}_2$ are denoted with $P_2{}^*$ and $\bar{p}_2{}^*$ respectively hereafter, where $\bar{p}_2{}^*$ is the value of $P_2{}^*$ divided by the projection area of the die in contact with the products.

The lubricant used is beef tallow with its frictional coefficient about 0.05 according to the ring compression test.

The specimen is compressed only with the upper punch as shown in Fig.1. During the working, the filling up into the die cavity always grows slowly toward the downside of the product rather than toward its upside. The filling up, therefore, is observed on the downside of the product.

4. Experimental Results and their Considerations

4.1 The two step method with the type C.D.-R.H.

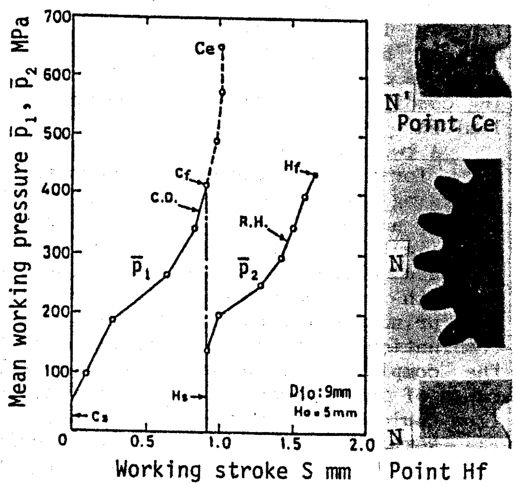
Figure 2(a) shows the filling up of the two step method with the type C.D.-R.H., where the blackened mark denotes the completely filled up state. When the specimen is worked only in the process C.D., the complete filling up can not be accomplished even when the pressure $\bar{p}_1$ is over 600 MPa. However, when the first step is halted at the point Cf and the second step using the process R.H. is resumed after boring a relief-hole of 9 mm in diameter, the complete filling up can be realized under 500 MPa in the pressure (which is given as the blackened mark). This state is clearly observed from the sectional photograph shown at the point Hf, and the photographs of the initial state and its transformation through the working are also shown in Fig.2(b).

Figure 2(c) shows the variations of the length A of the unfilled portion and the inside diameter D_i during the second step. Both the values of A and D_i get smaller with an increase of $\bar{p}_2$. This means that the filling up is carried out through combination of a centripetal flow with a centrifugal one, that is, through the divided flow.

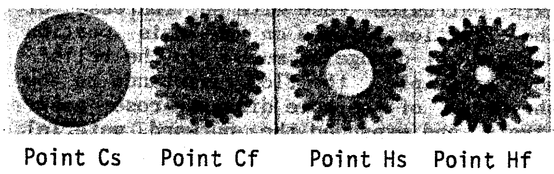
In the two step method, the completely filled up state is influenced extensively by the final pressure at the first step.

Figure 3 shows the influence of the final pressure $\bar{p}_1{}^*$ on the pressure $\bar{p}_2{}^*$ required for the complete filling up and the product height H^*. The value $\bar{p}_2{}^*$ falls remarkably with an increase of $\bar{p}_1{}^*$ and its reduction is intensified with an increase of the hole diameter D_{io}. The two step method, therefore, is an effective technique for precision die forging of a spur gear. The product height H^* grows to some degree with an increase of $\bar{p}_1{}^*$ but diminishes with an increase of D_{io}.

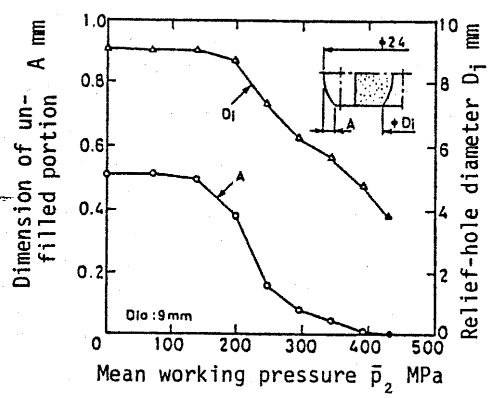
The same tool is used at each step in the two step method and it is preferable to reduce both the values of $\bar{p}_1{}^*$ and $\bar{p}_2{}^*$ for improving the tool-life. When the line



(a) Diagram of $\bar{p}_1$, $\bar{p}_2$ - S



(b) Photographs of the worked specimens at such points shown in the above (a)



(c) Diagrams of A - $\bar{p}_2$ and D_i - $\bar{p}_2$

Fig.2 Filling up behavior in the type C.D.-R.H.
(when the initial diameter Dio of the relief-hole is set at 9mm)

of 45° in the angle which keeps up the relation $\bar{p}_1^* = \bar{p}_2^*$ (called "the line M-M" hereafter) is drawn on Fig.3, the points where the line M-M intersects the line $\bar{p}_2^*-\bar{p}_1^*$ in each diameter D_{io} can be regarded as indicating the optimum combinations in the two step method. In these cases, it is preferable to make the hole diameter D_{io} as large as possible with a view to reducing the working pressure, but the larger D_{io} makes the product height the smaller, and this is not preferable for saving the material. In consideration of these conditions, the points X_1 and X_2 can be chosen as the most suitable combination under the experimental conditions.

4.2 The two step method with the type C.D-R.A.

Figure 4 shows the filling up in the two step method with the type C.D.-R.A. When the first step is halted and the second step using the process R.A. is resumed, the complete filling up, which is given as the blackened mark, can be as well recognized as in the case of the above mentioned type.

Figure 5 shows the variation of the pressure $\bar{p}_2^*$ required for the complete filling up and that of the product height H^* when the final pressure $\bar{p}_1^*$ is varied at the first step. When the axis diameter D_{io} is set under 10 mm, it is already confirmed, the complete filling up is not accomplished even when the pressure $\bar{p}_1^*$ is over 600 MPa.

A similar tendency observed in Fig.3 can be recognized also in Fig.5 and so the two step method proves useful in this type, too. Moreover, the optimum combination in the two step method can be given as the points Y_1 and Y_2 shown in Fig.5 through the same considerations as in the above section.

4.3 Comparison of the type C.D.-R.H. with the type C.D.-R.A.

Through the above experiments, it is confirmed that a spur gear can be formed precisely in various ways. In this section, the features of the types C.D.-R.H. and C.D.-R.A. are examined closely by comparing them with each other.

Figure 6, obtained from the above experiments, shows the filling up pressure $\bar{p}^*$ and the product height H^* at the optimum combination in the two step method. Figure 7, moreover, shows a diagram of $\bar{p}_1, \bar{p}_2 - S$ under the experimental condition close to the most desirable combination among those data of Fig.6.

These figures tell that the type C.D.-R.H. makes the value of $\bar{p}^*$ lower and that of H^* higher, that is, the type C.D.-R.H. is more effective than the type C.D.-R.A. both for improving the tool-life and for saving the material.

For a comparison, the diagram of $\bar{p}_1, \bar{p}_2$ -S of the barrelled disk specimen in another report[5] is shown again in Fig.8. In this case, the pressure at the blackened mark of the type C.D.-R.H. is nearly equal to that of the type C.D.-R.A. but the product

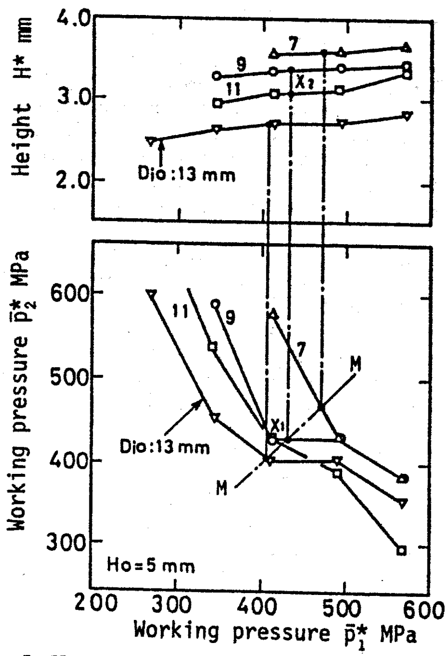


Fig.3 Influence of the pressure $\bar{p}_1^*$ on the pressure $\bar{p}_2^*$ and the height H^* at the completely filled up state (when the type C.D.-R.H. is used)

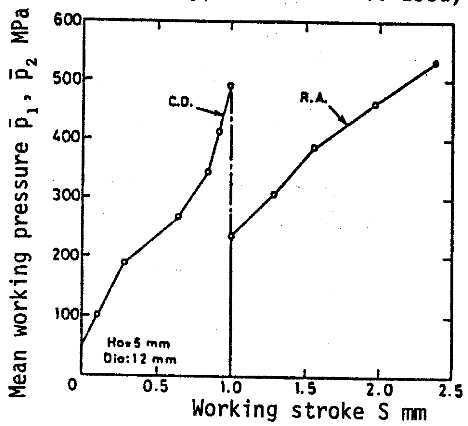


Fig.4 Filling up behavior in the type C.D.-R.A.
(when the diameter Dio of the relief-axis is set at 12mm)

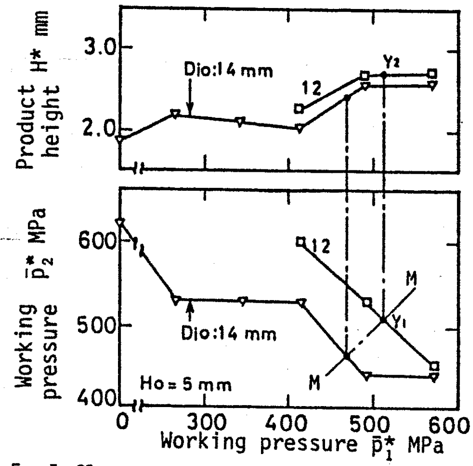


Fig.5 Influence of the pressure $\bar{p}_1^*$ on the pressure $\bar{p}^*$ and the height H^* at the completely filled up state (when the type C.D.-R.A. is used)

height of the former gets smaller than that of the latter because its completely filled up state appears later. This result is different from that shown in Fig.7, that is, the advantage of the product height in the type C.D.-R.A. disappears gradually in compliance with the complex contours of products. The reason must be explained in detail because of its significance.

As mentioned in another report,[3] the filling up into the die corner takes place in two modes basically as shown in Fig.9. One of these is a positive filling up through the component of the centrifugal flow and the other is a quasi-filling up in which the unfilled zone diminishes naturally under the depression. On occasion, the complete filling up may be accomplished only in the quasi-mode in the case of utilizing the two step forging method. But, it needs much more depression if the filling up in the first step is imperfect, and thus the product height diminishes much more. Especially, the outermost side of the specimen worked in the first step does not reach the wall surface of the container or when the length MN shown in Fig.9 remains zero, the complete filling up can not be attained only in the quasi-mode, whatever depression may be added to the specimen at the second step. For the purpose of an effective filling up, therefore, it is necessary to increase the ratio of the centrifugal flow, that is, to increase the resistance to the centripetal flow, thereby making the position of the flow division shift inward positively.

Now assuming that the depression of the first step is fully larger, the resistance to the centrifugal flow will be raised much more and the filling up at the second step will be performed mainly by the centripetal flow. The pressure-stroke curves shown in Figs. 7 and 8, therefore, can be considered to indicate the variation of the resistance to the centripetal flow with more depression. As mentioned already about the result of Fig.8, the pressure of the relief-axis principle R.A. rises in the upward convex curve and its increase gets less with more depression.[5] Variation in the pressure of the relief-hole principle R.H. becomes quite contrary to the above. This difference depends upon variation of the fractional reduction in area R of materials with more depression.

Generally, in the principle R.A., the direction of the centripetal flow turns to 90° in the angle because of its axis extru-

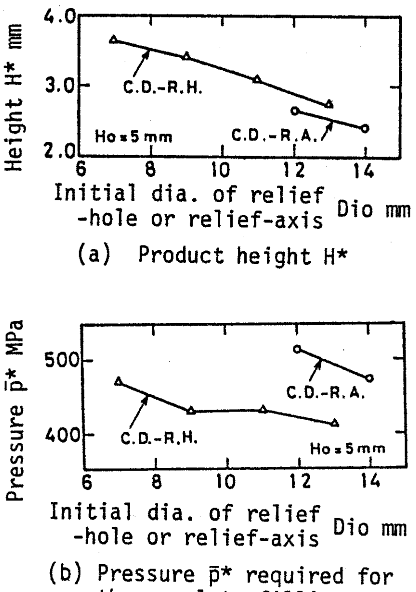


Fig.6 Variations of the pressure p* and the product height H* at the optimum combination in the two step method

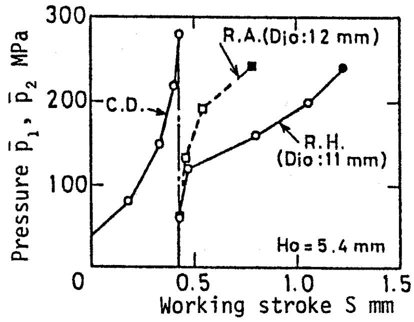


Fig.8 Diagrams of $\bar{p}_1$-S and $\bar{p}_2$ - S of the barrelled disk specimen in another report[4]

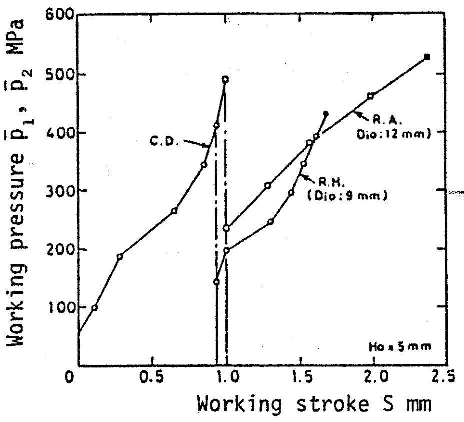


Fig.7 Diagrams of $\bar{p}_1$-S and $\bar{p}_2$ - S under the experimental condition close to the most desirable combination in Fig.6

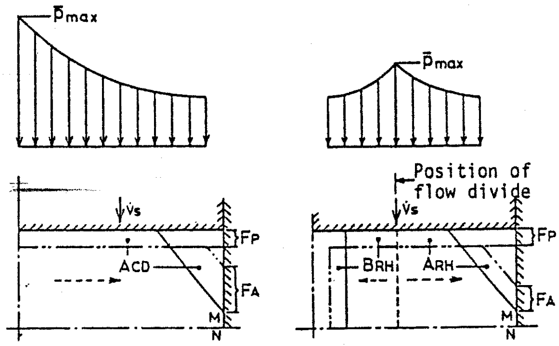


Fig.9 Schematic estimation of the filling up behavior into die cavity and the working pressure distribution
(where F_P denotes Quasi-filling up attained by depression and F_A does Positive-filling up done by the centrifugal material flow)

sion and therefore, a higher resistance to the centripetal flow exists at the start of the depression but the value R does not change because of the constant relief-axis diameter. On the other hand, in the principle R.H., the value R increases because the free surface portion of the material decreases owing to the shrinkage of the relief-hole.

From these features, the crossing state of each curve of the pressure comes to appear with more depression at the second step as seen in Fig.7.

If the material volume required for the complete filling up at the second step is smaller as compared with that in the case of the barrelled disk specimen, the filling up will be accomplished completely under a small depression, that is, before the crossing point as shown in Fig.8. Thus, the product height in R.A. becomes larger than that in R.H. On the contrary, in a spur gear, a much more centrifugal flow is required for the complete filling up in the second step and so the depression becomes longer, that is, the complete filling up will come to appear after the crossing point as shown in Fig.7. In this case, more increase of the resistance to the centripetal flow owing to larger R in the principle R.H. contributes to the earlier complete filling up, and thus the product height in R.H. becomes larger than that in R.A.

The above is the reason why the advantage of the product height in R.A. disappears gradually in accordance with complexity of the contour of products.

4.4 Influence of blank thickness Ho on the complete filling up

In this section, specimens of 3mm and 8mm in the initial thickness H_O are added newly to the experiment and the influence of H_O on the filling up behavior of the two step method is examined.

Figure 10 is the result about the type C.D.-R.H. when H_O=8mm. The variations of the pressure $\bar{p}_2{}^*$ and the product height H^* in changing the final pressure $\bar{p}_1{}^*$ of the first step and the relief-hole diameter D_{io} are all similar to those shown in Fig.3 (when H_O=5mm). The points W_1 and W_2 shown in Fig.10 can be also chosen as the optimum combination. The result is not shown here but the same tendency can be recognized when H_O=3mm, too.

Figure 11 shows the result about the type C.D.-R.A. when H_O=8mm. The variation tendency shown in Fig.11 is the same as that shown in Fig.5 and the optimum combination is given by the points V_1 and V_2. The result in the case of 3mm in H_O is the same, too.

Figure 12 shows the pressure $\bar{p}^*$ and the percentage H^*/H_{CD}^* *100 % at the optimum combination given throughout all of the above experiments, where H_{CD}^* is the height when the complete filling up is supposed to be attained only by the conventional closed die forging C.D.

In the type C.D.-R.H., the pressure $\bar{p}^*$ gets smaller with an increase of H_O and this is effective for improving the tool-life, but the product height H^* gets smaller and this is not effective for saving the material.

In the type C.D.-R.A., the same features as mentioned above can be observed, too but the pressure $\bar{p}^*$ falls when H_O=3mm. The reason is owing to formation of a recess.[2] That is, when the initial thickness of the specimen is too thin, the thickness ratio H_O/D_{io}, (where D_{io} is the relief-axis diameter), gets smaller and

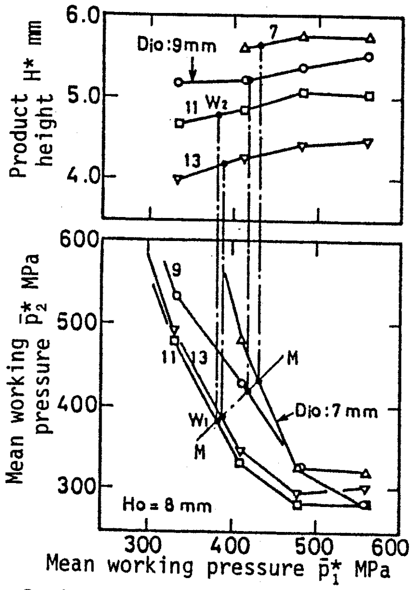


Fig.10 Influence of the initial thickness of used specimens on the pressure required for the complete filling up under the type C.D.-R.H.

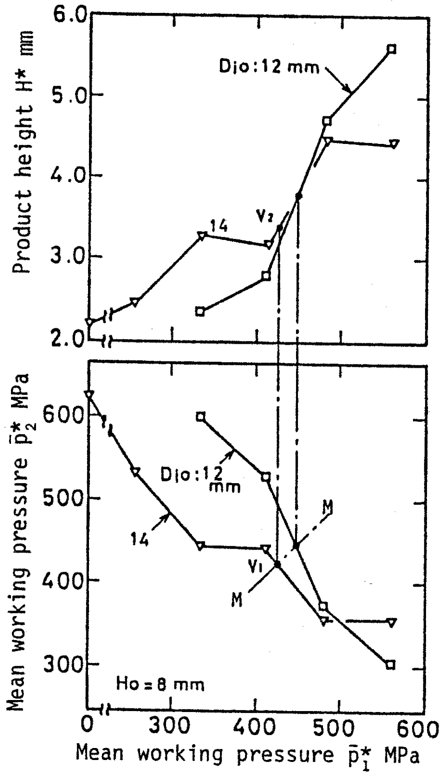


Fig.11 Influence of the initial thickness of specimens on the pressure required for the complete filling up under the type C.D.-R.A.

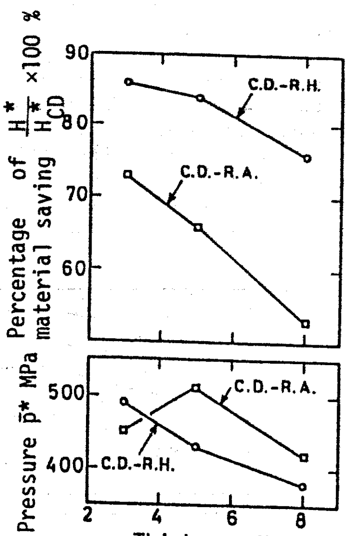


Fig.12 Filling up pressure $\bar{p}^*$ and the product height H^* at the optimum combination under the types C.D.-R.H. and C.D.-R.A.

this small value induces a buckling phenomenon within the central portion of the specimen during the axis extrusion. This phenomenon makes deformation easier and lowers the pressure. In other cases, this phenomenon does not occur and the deformation gets uniform and the pressure does not fall.

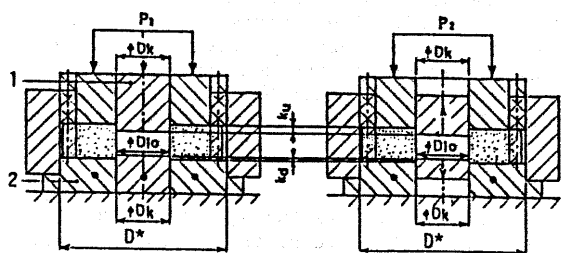
But generally speaking, the relief-hole principle is more effective than the relief-axis one and the process utilizing the divided flow has a wide application for the initial thickness of specimens.

4.5 Influence of the restriction of centripetal flow

As mentioned in the chapter 2, the flow restriction in the flow relief-hole principle was effective for the fundamental filling up model of a barrelled disk specimen.

This section intends to examine whether the flow restriction method is available also in actual machine parts, or not.

The experiment takes up two restriction types adopted in another report [6] as shown in Fig.13. One of them is the type where the step heights k_u and k_d, (which are given by the difference between the height of the mandrel and that of the punch), remain unchanged throughout the working. This type is called the type "k fixed", hereafter. The other is such that the mandrel is pushed back with the centripetal material flow, that is, the step heights k_u and k_d change during the working. This type is called the type "k free", hereafter. The experiment, moreover, is performed under the condition in which the specimen is compressed only with the upper punch as shown in Fig.13. In this case, filling up always grows more slowly toward the downside of the product than toward its upside. In this way, the condition of $k_u > k_d$ is also examined in this experiment. The experiment is carried out in the case



(a) Type "k fixed" (b) Type "k free"

(1 :Mandrel 2 :Fixed platen)

Fig.13 Restriction method of the centripetal material flow

Table 3 Dimensions of the adopted spline

Number of teeth	8
Face width	4 mm
Diameter of root cylinder Da	20 mm
Diameter of top cylinder D*	22 mm

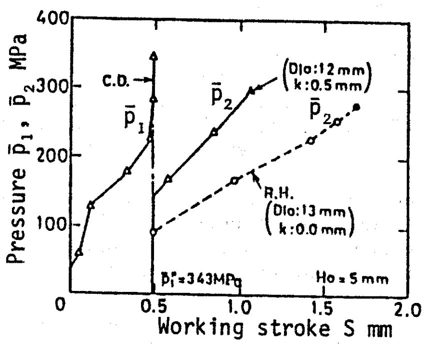
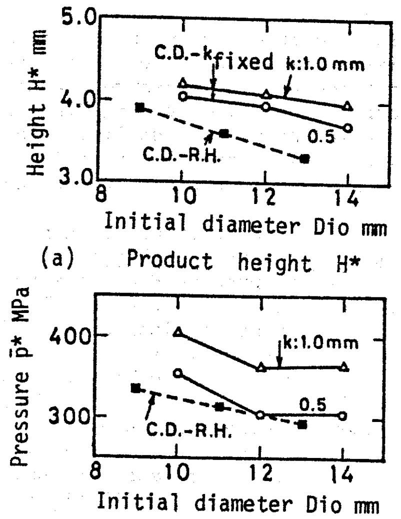


Fig.14 Comparison of the filling up behavior in the type "k fixed" with that in the process R.H. without any flow restriction (in the case of spline)

of the spline shown in Table 3 up to determination of the optimum combination of the two step method.

Figure 14 shows the compared result of the type "k fixed" with the process R.H. with no flow restriction under the two step method, where the dotted line shows the result of the type "k fixed", and where the solid one is that of the process R.H. and the addendum circular diameter D^* of the spline is set at 22 mm. The working pressure increases more in the type "k fixed" but the pressure required for the complete filling up, (which is given by the blackened mark), is nearly the same. This means that the complete filling up is attained earlier by the flow restriction and the product height also increases.

Figure 15 shows the variations of the filling up pressure $\bar{p}^*$ and the product height H^* at the optimum combination in the two step method, where the second step is in the type "k fixed". When the step height k $(=k_u=k_d)$ is set at 0.5 mm, the flow restriction makes the product height H^* much larger without raising the pressure $\bar{p}^*$. When the step height k is varied to 1.0 mm, the flow restriction also makes the product height H^* larger and makes the pressure $\bar{p}^*$ larger as well, that is, the



(b) Filling up pressure $\bar{p}^*$

Fig.15 Variations of the filling up pressure $\bar{p}^*$ and the product height H^* at the optimum combination in the two step method

(when D^* of the addendum circle in the spline is set at 22 mm)

flow restriction is not desirable in this case.

After all, the condition of Dio =12 mm and k =0.5 mm can be chosen as the best one in this type. This condition is the same as the optimum one obtained with the barrelled disk specimen in another report.[16]

As mentioned above, filling up always grows slowly toward the downside of the product because of its adopted punch motion. Therefore, promotion of the downward material flow is necessary for an effective filling up. This promotion will be achieved by setting the lower step height k_d smaller than the upper one k_u . The examination result is shown in Fig.16. The optimum combination of the two step method can be picked out of the blackened circular marks on the line M-M in the relation of $\bar{p}_1{}^* = \bar{p}_2{}^*$ as mentioned in another report.[5]

The filling up pressure on the line M-M in the condition of k_u=0.5mm and k_d=0.0mm falls, and so the condition of $k_u > k_d$ is desirable for decreasing the pressure. Nevertheless, the product height H^* gets smaller in this case. On the contrary, when $k_u < k_d$, it is confirmed, the filling up becomes harder and a high pressure is required for the complete filling up.

The same experiment as mentioned above is performed in the case of the type "k free", too.

Figure 17 compares the results about each type, when the values of $\bar{p}^*$ and H^* are those of the most desirable combination in the two step method.

On the basis of the condition a with no flow restriction, the condition b in the type "k fixed" makes the product height H^* much larger without raising the pressure $\bar{p}^*$. The condition c which keeps the relation of $k_u > k_d$ decreases the product height and lowers the pressure $\bar{p}^*$. In the type "k free", the conditions d and e , (both of which keep $k_u = k_d$), are not desirable for the complete filling up.

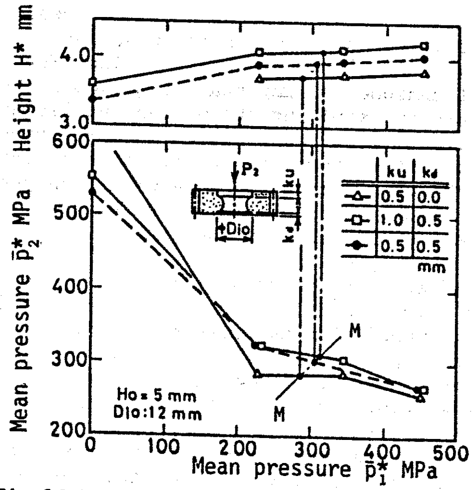
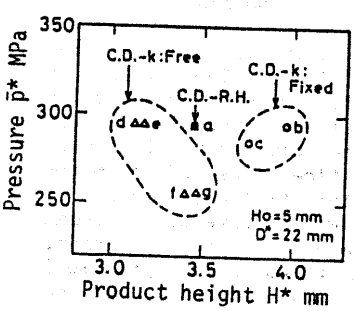


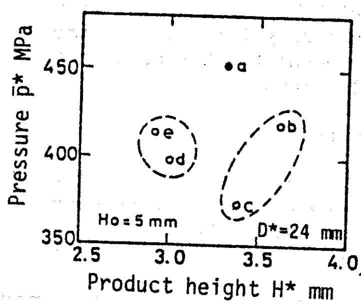
Fig.16 Validity of interchanging the values of the step heights k_u and k_d in the case of a spline



	Method	k_u	k_d
a	C.D.-R.H.	0	0
b	C.D.- k:Fixed	0.5	0.5
c		0.5	0.0
d	C.D.- k:Free	0.5	0.5
e		1.0	1.0
f		0.5	0.0
g		1.0	0.5

(mm)

Fig.17 Validity of flow restriction in the case of a spline



	Method	k_u	k_d
a	C.D.-R.H.	0	0
b	C.D.- k:Fixed	0.5	0.5
c		0.5	0.0
d	C.D.- k:Free	0.5	0.0
e		1.0	0.5

(mm)

Fig.18 Validity of flow restriction in the case of a spur gear

Only the conditions f and g, (where $k_u > k_d$), make the pressure $\bar{p}^*$ much lower without decreasing the product height H^*.

Based on the above data of the spline, the flow restriction method is applied to a spur gear. The obtained result is shown in Fig.18.

Under the condition a as mentioned above, the flow restriction method is effective for decreasing the filling up pressure $\bar{p}^*$ in each type. But the product height H^* is improved only by the type "k fixed" and not by the type "k free". In the type "k fixed", moreover, the condition b ,(where $k_u = k_d$), is more effective for improving the product height. On the other hand, the condition c, (where $k_u > k_d$), is more effective for decreasing the filling up pressure.

From the above, the flow restriction

is confirmed to be useful for decreasing the filling up pressure and also for increasing the product height. Therefore, this technique is important and should be included in applying the process utilizing the divided flow. But the optimum restriction condition for forming of each product must be chosen in accordance with shapes of products because their usefulness is influenced heavily by the shapes of the products.

After the process utilizing the divided flow is established as an actual useful manufacturing process, it must be examined precisely how to incorporate the working process of the relief-hole into the whole working. In this case, the applicability of the flow restriction technique will also change according to that of the hole working. A suggestion on this subject will be presented in near future. The authors want to emphasize the usefulness of the flow restriction.

In conclusion, the possibility of the precision die forging of a spur gear by use of the process utilizing the divided flow is summarized as follows. The filling up pressure shown in Fig.18 can be reduced to a value corresponding to about 3.2 in the fractional pressure divided by the uniaxial compressive flow stress of the material in the completely filled up state. If the product is allowed to have about 0.05mm in the unfilled dimension at the outermost corner of all the products in practical application, the above pressure can be decreased more and the applicability to actual materials can be considered to be wide enough. The dimensional accuracy of forged products will be defined in near future and the accuracy for the time being is set nearly equal to that of a cut spur gear of the 5th class in JIS.

5 Conclusions

A process utilizing the divided flow proposed newly was applied to the precision die forging of a spur gear. Following conclusions are obtained from the experimental examinations.

(1) The two step forging method enables the precision die forging of the spur gear under a low working pressure, when a preliminary closed die forging C.D. is combined with the process utilizing the divided flow by using the flow relief-axis principle R.A. and the flow relief-hole one R.H.

(2) In the precision die forging of the spur gear, the type combining the process C.D. with the process R.H. is more desirable for decreasing the pressure $\bar{p}^*$ required for the complete filling up and for increasing the product height H^* than the type combining the process C.D. with the process R.A. This result is different from that of a barrelled disk specimen, and the process R.H. becomes more useful for improving the tool-life and for saving the material in accordance with its complexity of the products.

(3) The process utilizing the divided flow is also useful in the case of changing the thickness of sheet materials, and the applicable range is comparatively wide. While the thickness grows up, the pressure $\bar{p}^*$ decreases much more but the product height H^* does not increase.

(4) The restriction of the centripetal material flow in the process C.D.-R.H. is very effective for improving the tool-life and for saving the materials. This technique, therefore, is desirably applied positively in actual production fields.

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