SOME REMARKS ON THE MANUFACTURE OF STEEL FORGINGS.

The production of heavy forgings to meet the rapidly increasing sizes of power and transmission units in naval engineering of late years has been accompanied with the almost entire absence of failure on service; this points not only to satisfactory factors of safety having been introduced in design, notwithstanding the exacting limitations in weight allowed, but also to the necessary care and control having been exercised in manufacture. Defects in some cases existed in the material, or have developed in it during the manufacture of the forgings concerned, but the precautions in force have ensured their discovery in time to prevent the forgings being put into use.

To provide large forgings it follows that large ingots are required and it is proposed therefore to deal with the manufacture of these rather than that of small ingots, and to refer to some of the difficulties that arise on account of the large masses of steel employed, and to some of the defects that may develop.

To lead up to this, a few preliminary remarks are perhaps advisable.

The steel used for large forgings for Naval engineering purposes is, as is generally known, made in the Siemens acid open hearth furnace. Pure grades of pig iron and steel scrap are used and the furnace charges are usually of about 40 to 60 tons in weight.

So that to produce, say, a 100 ton ingot, such as has been required for some of the larger sizes of shafting, the steel has to be melted in two heats and these must be ready for teeming into one ingot mould at the same time.

In view of subsequent remarks, it must be borne in mind that it is essential for the operator to have the chemical reactions in the steel-making furnace sufficiently under control, to ensure the complete and satisfactory de-oxidising and refining of the steel before tapping.

Referring to ingots generally, the manufacturer must satisfy himself that the design of the mould as to shape and dimensions is satisfactory, and in this connection it may be mentioned that the best practice is now considered to be to cast with the broader end of the ingot at the top.

The temperature of the steel when cast and the size of the nozzle (which regulates the speed of pouring from the ladle to the mould) are also most important considerations in producing a sound ingot.

Though not all, these are perhaps the principal points to be observed, so that as the liquid steel in the ingot cools down to the freezing point, and then gradually solidifies throughout, the contraction shall take place in such a manner that the ingot formed shall be sound and free from any shrinkage cavity in that part of it which is to be employed in forging after the intended discard has been made.

For large ingots, particularly say of 5 tons and upwards, it is now the general practice in making steels for all special purposes to use a refractory head. By this is meant that the upper part of the mould is lined with fireclay or a similar substance of a highly refractory nature, with the result that the steel in this portion of the ingot remains in the liquid condition and can feed into the lower portion as it freezes so as to prevent, as far as possible, the formation of objectionable cavities. The dimensions and method of using this head are matters requiring careful attention and forethought.

Shrinkage cavities and segregates are unavoidable but the object aimed at is to locate them at the top scrap end of the ingot and at the same time to limit their extent as far as possible.

In small ingots the chilling effect of the mould is such as to accentuate the preliminary freezing of the steel at the bottom and sides of the ingot, and so to materially assist in the proper location of the shrinkage cavity and segregate.

The same principle of freezing operates in large ingots, but it will be seen that with a greater mass the process is less under control and, with these large ingots particularly, the impurities which the liquid steels hold in solution when run into the mould, frequently do not segregate together at the shrinkage cavity at the top of the ingot, but are partly trapped in other parts of it during the freezing process.

So it often occurs that on examination in the machine shop, these impurities, further drawn out during forging, show longitudinal markings colloquially known as "ghosts." It is therefore necessary to understand the nature of these markings and of their influence on the strength of the material, so that a well considered opinion may be given as to whether the forging concerned should be accepted as serviceable or not.

The following mechanical tests have been taken from two steel forgings, the material of which, though of slightly different analysis, had been forged in a similar manner—ghosts showing on the machined surfaces in each case. The results obtained may be taken as illustrating the effect of segregation on the physical properties of the two forgings.

Case 1. Test pieces taken along and at right angles respectively to the line of axis of the "ghosts" gave the following results :—

——	Yield Point, tons/sq. in.	Maximum stress, tons/ sq. in.	Elongation.	Reduction of Area.
			Per cent.	Per cent.
Longitudinal -	35·2	45·2	23·0	52·0
Transverse -	34·6	42·0	14·0	24·0

It will be seen therefore, that in this instance, the occurrence of these segregated areas has the effect of materially reducing the ductility of the steel in the transverse direction.

Case 2. Test pieces taken as before gave :—

——	Bend.	Maximum stress, tons/ sq. in.	Elongation.	Reduction of Area.
	Deg.		Per cent.	Per cent.
Longitudinal - -	180	35·6	26·5	50·0
Transverse - -	180	35·1	26·5	51·0

In this instance, the defect produced by segregation had apparently no detrimental influence on the physical properties of the steel, so that there appears to be some particular reason why in some cases the ghosts materially affect the physical properties whilst in others they do not do so.

A careful consideration of this matter leads one to the conclusion that if the ghosts have occurred towards the outside of the ingot their effect upon the mechanical strength is generally small, no doubt owing to the fact that such ghosts, whilst consisting of segregated material, contain usually only a small increase in the impurities over the average condition of the material. This condition was illustrated in Case 2. When segregated material in the centre of the ingot comes to be considered it is found that as the material at such areas must have frozen at a much later period than that towards the outside of the ingot, it is proportionately higher in impurities and therefore the physical properties of the material are considerably affected owing to highly segregated areas frequently becoming of a definitely porous nature.

This condition was illustrated in Case 1, where there was marked difference between the longitudinal and transverse tests and the ghosts in evidence were really associated with the centre of the ingot.

With regard to the composition of these segregates, spoken of as ghosts, as compared with the analysis of the average material of the forging,—

The carbon content may be up or down.

The silicon content is likely to be up on account of the probability of the slag contained in the segregate.

The sulphur and manganese probably up and shewing as manganese sulphide.

The phosphorous probably up and in solution in the ferrite.

With regard to the forging operation, *i.e.*, the hammering, pressing or rolling of the steel to shape, it is clear that to produce a satisfactory forging two conditions are necessary, viz. :—

(1) That the ingot as supplied to the forge shall be sound, and

(2) That the forging operation shall be satisfactorily carried out.

Dealing with these in turn :—

(1) As stated in the earlier part of this article, conditions such as an ingot mould of unsuitable shape, or unsatisfactory feeding arrangements, may result in the formation of an internal cavity down the body of the forging, also there may be excessive slag inclusions owing to the segregation of impurities taking place otherwise than in the top part of the ingot, which has been discarded before the forging operation.

There may develop during forging, cracks which were caused in the ingot owing to the speed of casting and the temperature of the steel when cast being unsuitable, or cracks resulting from flaws that were in the surface of the ingot and caused by it sticking to the mould. Also it has been explained that on account of the difficulties of manufacture of large ingots as compated with small ones, such defects are more likely to be found and to be of a more serious nature in the former than in the latter. In both cases, it is evident that if an ingot containing even minor cracks is heated up to the forging temperature and then put under the hammer or press, these cracks may open up into quite serious defects; it is therefore necessary if such a piece of steel is to be made further use of, that the ingot or bloom should be machined on the surface before forging so that all traces of cracks are first removed.

(2) To readily and satisfactorily forge the steel ingot into the shape required it is necessary to raise it to a sufficiently high temperature.

Whereas for instance the steel from which a propeller shaft is made has a tensile strength of 28/32 tons per sq. in. at ordinary temperatures, accompanied by an elongation of 25 per cent. when that steel is heated to a temperature of 1,050°/1,100° C. its ultimate stress in tons per sq. in. is reduced to about 1½ tons, and its capacity to elongate goes up to 80/90 per cent. with a reduction of area of 95/99 per cent. Therefore when the steel is raised to such temperatures it is in an extremely plastic and yielding condition.

From 1,050/1,150° C. are desirable temperatures for commencing the forging operation. Having reached that condition, as a result of temperature, in which the capacity of the material for being hammered or pressed to shape is perfectly satisfactory, higher temperatures only lead to the ruin of the steel by its becoming burnt. By this is meant that rapid oxidisation of the surface of the metal takes place and also extends into the material between the crystals. This oxide of iron is of low tenacity and of considerable brittleness, and as it cannot be removed by subsequent heat-treatment material in this condition is comparatively easy to rupture.

An important aspect of the operation is that in heating, sufficient time should be given for the heat to soak very thoroughly through the mass. This is particularly important when dealing with the larger forgings, since it is possible for the outside of a forging to appear sufficiently hot whilst the inside may not have attained the degree of plasticity necessary.

Once the suitable forging temperature is reached the amount of deformation that can be safely given to the steel at each application of pressure during the forging operation, is very considerable but is largely a matter of experience. Also the work should be put on the ingot with due consideration of the nature of the completed article and of the stresses it will have to withstand, also that as far as is possible the centre or weakest part of the original ingot, and which also contains the most impurities, shall coincide with that part of the finished forging which is to be subjected to the least stress.

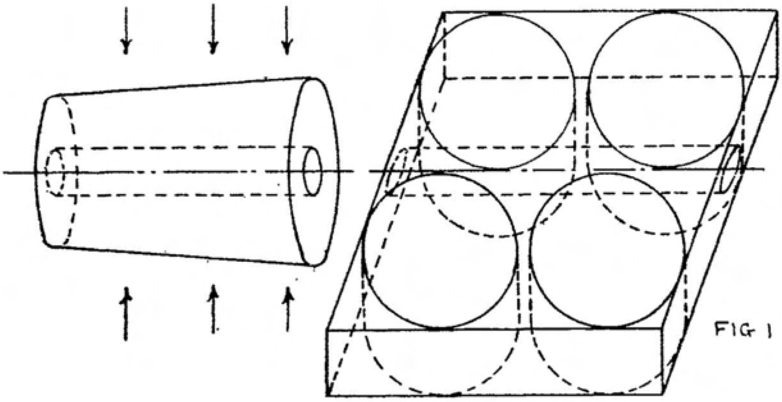

FIG 1

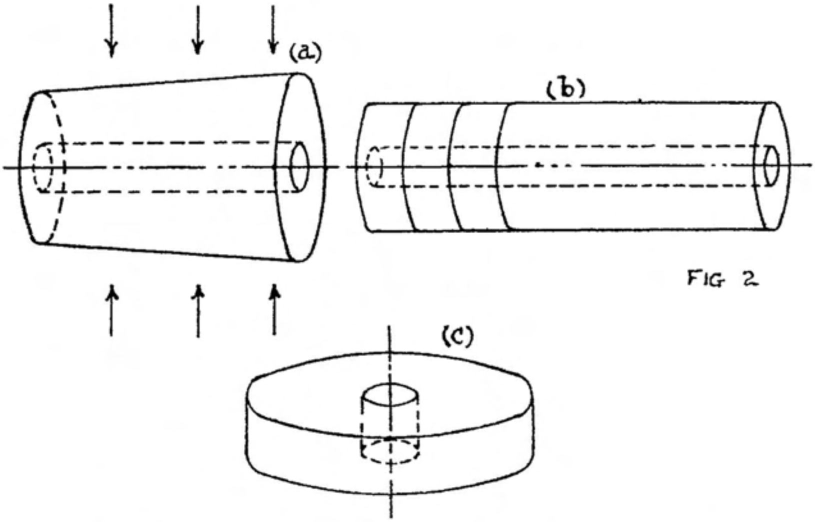

FIG 2

As an example of (1) incorrect and (2) correct methods of forging a turbine disc :—

> (1) The ingot is flattened by applying pressure as shown and discs are cut so that in the finished forging the centre of the ingot passes through plane of the discs and near the circumference of each as shown.
>
> (2) The ingot (*a*) is "cogged," *i.e.*, partly forged, to produce a long cylinder of steel, (*b*). From this the discs are sliced out, turned with the flat faces horizontal, and forged as shown at (*c*).

The material is thus well worked, it flows outward during the forging process and the material that formed the centre of the ingot now passes vertically through the centre of the disc, and so coincides with that part of it which is removed.

Finally the temperature at which the forging operation is abandoned is most important.

This temperature is determined by experience for steel of a particular quality, it being quite clear that if forgings are hammered or pressed when too cold, not only is abnormal consumption of energy required for the necessary deformation, but an actual cold working effect may be produced, and working at too low temperatures tends to cause internal stress in the material.

That is to say the crystals of the material would not only be deformed but in some cases actually broken down so that further work on it in this too cold condition would result in rupture.

Carbon steels are put in their best condition by heat-treatment after forging to remove internal stresses, and also to put the material in a uniform condition from a metallurgical point of view.

This process is usually called "normalising," it consists in heating the forging to from 25° to 50° C. above the upper critical point, say 825° to 875° (according to the quality of the steel) keeping it at that temperature only a sufficient period to heat the steel through, then cooling it in air away from draughts.

Three critical points exist in the mild carbon steels largely used for marine forgings, but the highest is the most important to consider, and may be described as that temperature which must be reached so that the renewal of the crystalline structure may take place which is necessary in order that the steel may be restored to its best condition.