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# COMPARATIVE STUDY OF HOT WORKED DIE STEEL H13 PRODUCED BY A NEW TECHNOLOGY

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## ABSTRACT

This paper contains a comparative study of the die steel characteristics of both new technology (Osprey) and conventionally produced H13 hot worked die steel. Die-life, cost analysis, metallographic and fractographic examination were performed on 5% chrome steel H13 of Osprey dies which hot forged to a different reduction and then heat treated to a hardness of 42 RC with a case nitriding depth of 80 microns.

## INTRODUCTION

The pressures on the metal forming industry to reduce its costs, improve material utilization and to increase its efficiency are probably greater today than at any other time. Forgings of die steel are now produced by two basically different methods: the forging of prerolled bar stock and by powder forging means as shown in Fig. 1. The forging of prerolled bar stock is the most common method of production and consists of melting, casting into ingots, rolling into bar, cutting into slugs, reheating and then forging. This route, however, generates large quantities of scrap particularly from cropping and clipping operations and this scrap is as expensive to produce as the forging themselves [1]. Powder formed components tend to be expensive, as many process stages are often needed to convert molten metal into a usable product. A typical route for the production of forging could consist of melting, water atomized, drying, sieving, reducing, blending, compacting, sintering and then forging. For both forging routes [1-6] the raw material costs (i.e. bar stock or powder) are a major proportion of the production costs and therfore, considerable efforts are being made on the one hand to maximise the use of expensive feed stock and on the other to reduce the cost of the feed stock.

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With these aims in view, a novel method of producing feedstrock suitable for forging is now being developed by Osprey Metals Ltd., in conjunction with Birmingham University, U.K., which could offer significant economic and technical benefits to the forging industry. A comparison between conventional forging, powder forging and Osprey forging routes [7-12] are shown in Fig. 1. The aim of the present work is to study the die steel characteristics of both Osprey and conventionally produced H13 hot worked die steel. In this paper, the author is mainly concerned with the die life, metallographic and fractographic examination of 5% chrome steel of Osprey preforms which hot forged to a different reduction in height up to 50%. The author is also concerned with the cost analysis of both Osprey and conventionally produced, H13, hot worked die steel in order to estimate the possible savings/tonne.

| | Conventional Forging | Powder Forging | Osprey Forging |
|---|---|---|---|
| | - Melting | - Melting | - Melting |
| | - Casting | - Atomizing | - Gas atomized to collector mould |
| | - Rolling | - Drying | - Sieving |
| | - Cutting | | |
| | - Reheating | - Reducing | - Qualifying furnace |
| | | - Compacting | |
| | | - Sintering | |
| | - Forging | - Forging | - Forging |
| Material utilization | 40 - 50% | 5 - 10% | 10 - 15% |

Fig. 1. Comparison between conventional, powder and Osprey forging routes.

## PLANT AND EQUIPMENT

The Osprey process [8 & 9] essentially consists of three operations, namely, melting, gas atomising/depositing and hot forging as shown in Fig. 1.

### Melting Operation

200 KW induction furnace was used to melt and dispense liquid metal into the gas atomizer which is located at the top of the spray chamber.

### Atomizing/Depositing Operation

A pilot production plant of atomizing/depositing have been designed by Osprey Metal Ltd. This plant consists basically of a heated tundish, an atomizing device with associated gas control equipment, preform collector and automatic removal.

All reheating operations were carried out in an Efco-Royce 12 KW molybdenum wound furnace with a tube diameter of 200 mm and a uniform heating zone 230 mm long. A cracked ammonia gas was passed through the furnace at a flow rate of 0.5 $m^3$/hr.

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## Forging Machine

The Osprey preforms were forged on a MKII Petro Forge machine [13] having a velocity range at impact of 4-5 m/sec. and maximum load of 6000 KN.

## Material Used

Osborn hot work H13 bar stock was used throughout the tests in order to compare between the conventional and Osprey produced die steel. A typical analysis of Osborn H13 was: 0.39 C; 1.0 Si; 5.0 Cr; 1.4 Mo; 1.0 V.

# EXPERIMENTAL RESULTS AND DISCUSSION

The tests described were performed to compare the characteristics and properties of hot worked die steel H13 produced by Osprey process with the conventionally produced one. A considerable number of variables is involved in such an analysis: The chemical analysis of metal, temperature of molten metal, bore diameter of ceremic nozzle, rate of flow of molten metal, type of atomized gas, pressure of atomized gas, temperature of atomized gas, rate of flowing gas, distance between the atomizer and collector, forging temperature, type of forging die and impact velocity all play their part. Some of these variables were readily eliminated by selecting Osborn hot work H13 bar stock for all tests performed of both Osprey and conventionally produced H13, the molten metal was poured at 1600 °C through a 5 mm diameter ceremic nozzle at a rate of 10 kg/min., the metal stream was atomized by nitrogen gas of flowing rate of 2.7 $m^3$/hr and 1 MPa pressure at room temperature [10], the mild steel collector die was placed in the spray at a distance of 300 mm from the atomizer [8-11]. For the sake of simplicity, it was decided to cool all the preforms inside the chamber in a nitrogen atmoshpere. Some of the preforms were reheated in a cracked ammonia atmosphere and forged to the finished shape in one blow using the Petro Forge machine. Both the forged and unforged product were annealed at 900 °C and furnace cooled to a usual annealed hardness, 207-217 BHN. At this stage the preforms, as sprayed for sprayed/forged were now in a condition which would be as conventional billet used for die production, so any subsequent operations would be the same for the Osprey samples as normal billet steel.

## Effect of Reheating Temperature Prior to Forging on the Spray Preform Characteristics

Reheating temperatures of 1200, 1100, 1050 and 1000 °C were used in order to determine the optimum forging temperature of H13 sprayed preform as far as the microstructure and fractographic examinations were concerned. Preforms of H13 hot worked die steel were prepared by Osprey process under the above mentioned spraying/depositing conditions, then reheated in a cracked ammonia atmosphere for 20 min. and forged in a closed die to the same reduction in height and then sand cooled. The results of this series of tests show that the preform which forged at 1000 °C was scattered to many pieces while the one forged at 1050 °C was partly cracked. However, the preforms reheated to a temperatures of 1100 and 1200 °C prior to forging were successfully forged. Samples for microstructure were prepared from the middle of each forged product as well as a fresh fracture surface for fractographic examination. For microstructure examinations all the samples were elecrolytically etched using oxalic acid reagent.

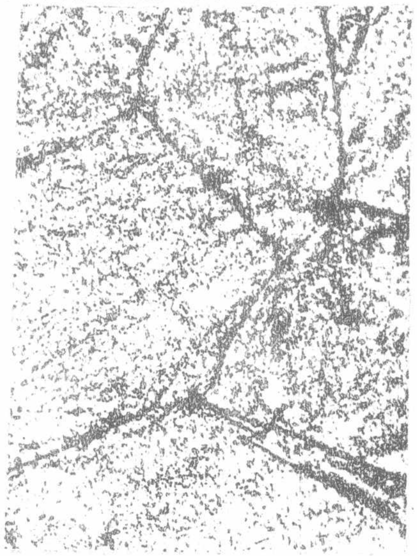


Fig 2a. Microstructure x 200

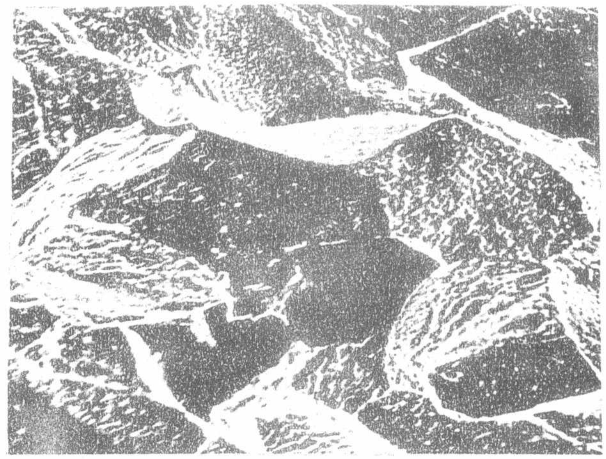


Fig. 2b. SEM of fracture surface x 200

Fig. 2. Structure and fracture of Osprey H3 forged at 1200 °C.

Fig. 2a and 2b show the microstructure and the fracture surface of the forged preform at 1200 °C respectively. The microstructure exhibits a complete carbide network at the grain boundaries and shows an internal structure of chromium iron ferrite containing carbides particles. The grain growth shown in Fig. 2a is mainly due to the effect of over heating prior to forging process. Moreover, large intergranular overheating facets are observed on the fracture surface (Fig. 2b). The size of the facets corresponds to that of the grains of austenite at the hot working temperature. The facets consists of numerous fine ductile dimples which are nucleated by very fine particles of MnS. This is because when alloy steels are heated to temperature in excess of 1150 °C manganese sulphide inclusions start to dissolve in the austenite. Their solubility increasing with increasing temperature. On subsequent cooling, the sulphur solid solution in the austenite is then re-precipitated as fine particles of MnS at the austenite grain boundaries.

Fig. 3a. Microstructure x 650

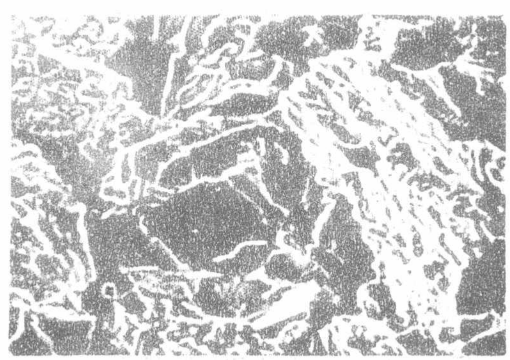


Fig. 3b. SEM of fracture surface x400

Fig. 3. Structure and fracture of Osprey H13 forged at 1100 °C.

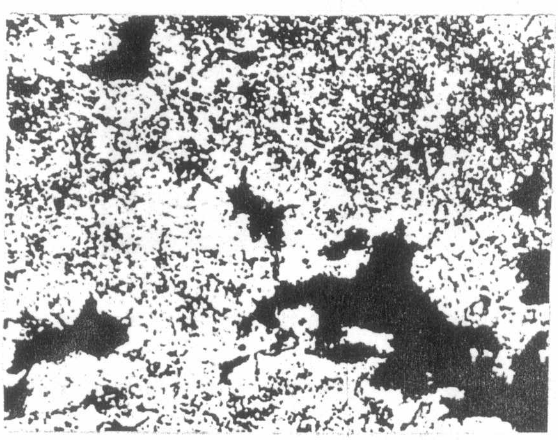
Microstructure and fractographic of the forged preform at 1100 °C are shown in Fig. 3a and 3b. The microstructure exhibits a chromium iron ferrite with coalesced carbide particles. Incomplete carbide network was also observed and the separation of a carbide constituents has occurred at the grain boundaries and there was no evidence of grain growth. The general mode of fracture shown in Fig. 3b was integranular fracture with trasgranular fracture of both cleavage facets with river pattern and few elongated dimples.

From the above observation, it was decided to reheat the preforms to a temperature of 1100 °C prior to forging for any further investigation.

## Effect of Forging Process on the Spray Preform Characteristics

Osprey produced H13 alloy steel preforms were reheated to 1100 °C in a cracked ammonia atmospher. Cylindrical preforms were produced from the furnace and forged either between flat dies or in a large diameter closed die to the same reduction in height, while the other were cooled without forging. All the samples were annealed at 900 °C for one hour and furnace cooled.

The microstructure of an annealed etched preform as sprayed was shown in Fig. 4a, while the fracture mode was observed in Fig. 4b. A normal structure of chromium iron ferrite containing carbide particles was observed with a complete absence of the original particles boundaries. However, a porosity inclusions which were occurring in spraying process (5%) were visible. The porosity occurred more towards the base of the preforms and also towards the outer skin. The concentration of porosity at the base can be attributed possibly to the collector plate in the spraying process taking too much heat out of sprayed particales. The fractograph (Fig. 4b) shows that the pores were non-uniform in size and quite angular in shape.



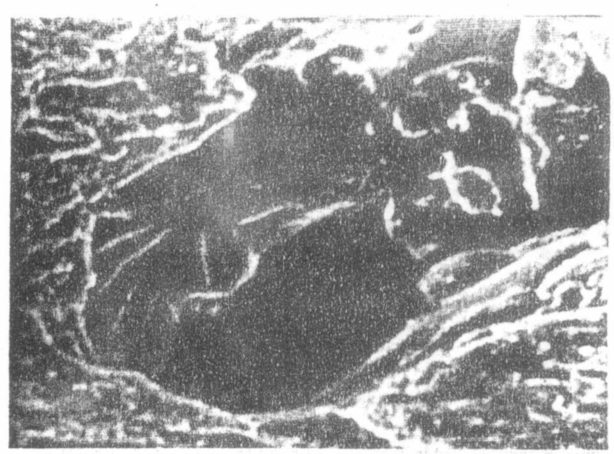


Fig. 4a. Microstructure x400 Fig. 4b. SEM of fracture surface x600

Fig. 4. Structure and fracture of Osprey H13 annealed preform.

In structure examination the effect of hot worked preform to a 50% reduction in height between flat dies had reduced the porosity content as shown in Fig. 5a. and flaten the pores in the direction of forging as shown in Fib. 5b when compared with Fig. 4b. However, the effect of hot working the preform in a closed die had nearly eliminated the porosity content as shown in Fig. 6a and 6b.

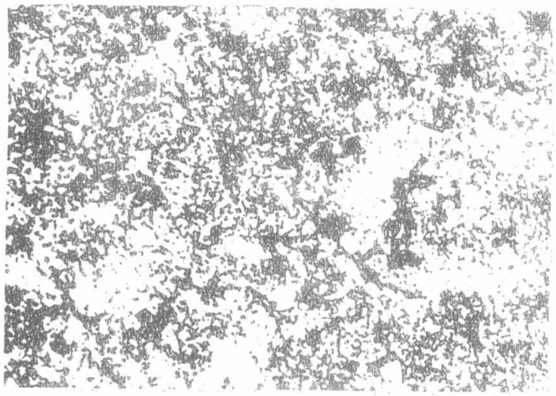


Fig. 5a. Microstructure x 400    Fig. 5b. SEM of fracture surface x 600

Fig. 5. Structure and fracture of hot forged preform between flat die.

Fig. 6a. Microstructure x 400    Fig. 6b. SEM of fracture surface x 600

Fig. 6 . Strucuture and fracture of hot forged preform in closed die.

Production Run

The die chosen was the Massey pin pump support shown in Fig. 7c, this die being the smallest Garrington Ltd. manufacture and the largest Osprey Ltd. can manufacutre at present. In order to eliminate the 5% porosity

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which exists in the sprayed/deposited preforms as well as to make the preforms to size, it was thought possible to hot work them at 1100 °C after spraying in a closed die of 120 mm bore diameter. This had the effect of knocking the preforms down and spreading the diameter as shown in Fig. 7a. and 7b. All the forged preforms were annealed and at this stage the forged preforms were now in a condition which would be a normal billets used for die production. The dies were then prepared and heat treated to 42-44 RC with nitriding the die impression, following the same treatment as conventional H13 die steel.

Thirty dies of each Osprey and conventional procuded H13 were tested by Garrington Ltd (1).

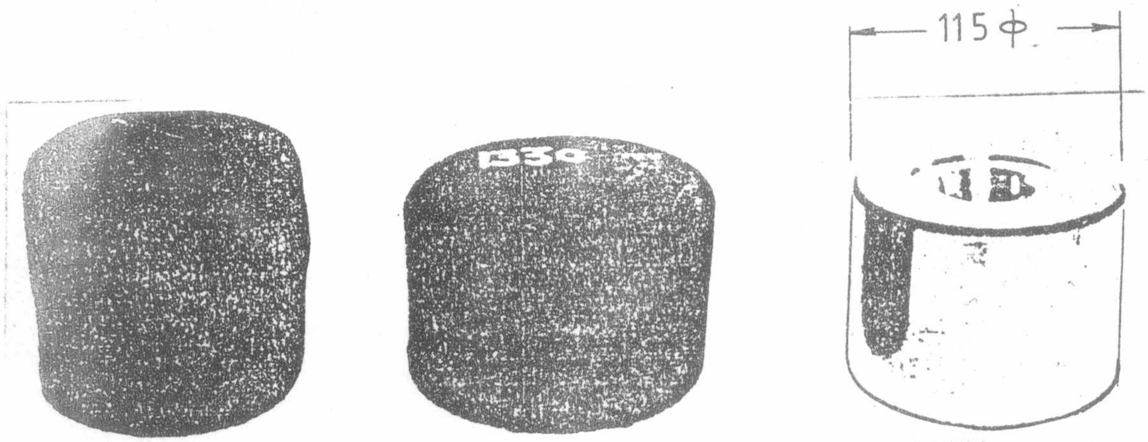



Fig. 7a. Preform     Fig 7b. Forged     Fig. 7c Machined

Fig 7. Sequence of preparing Massey pin pump support die after spraying.

Fig. 8 shows the distribution of die lives for both Osprey and conventional produced H13 die steel. From the histogram of both cases, it can be seen that the mean die lives of Osprey dies was 3500 forgings to a limit of confidence of 425, while the mean die lives of conventional dies was only 3316 forgings to a limit of confidence of 411. Therefore, the Osprey dies were comprable well with the conventional dies as far as the die lives was concerned. However, as can be seen from Fig. 8, one of the Osprey dies had a very poor die life of 250 forgings only. Therefore, a sample was prepared for macro examination and this revealed that the surface treatment was very poor and possibly there had been none at all. It also revealed that the surface had been subjected to excessive heat and could suggest sticking forging in the die. However, metallurgically the structure was good compared to conventional H13 die as shown in Fig. 9z and 9b respectively. The Osprey material showed a uniform structure of carbide in a structureless ground mass of martensite without any segregation which normally exist in conventional H13 as shown in Fig. 9b. Heat treatment was also satisfactory and a hardness of 44 RC was recorded. The early failure of this die can only be attributed to the lack of case nitriding impression treatment.

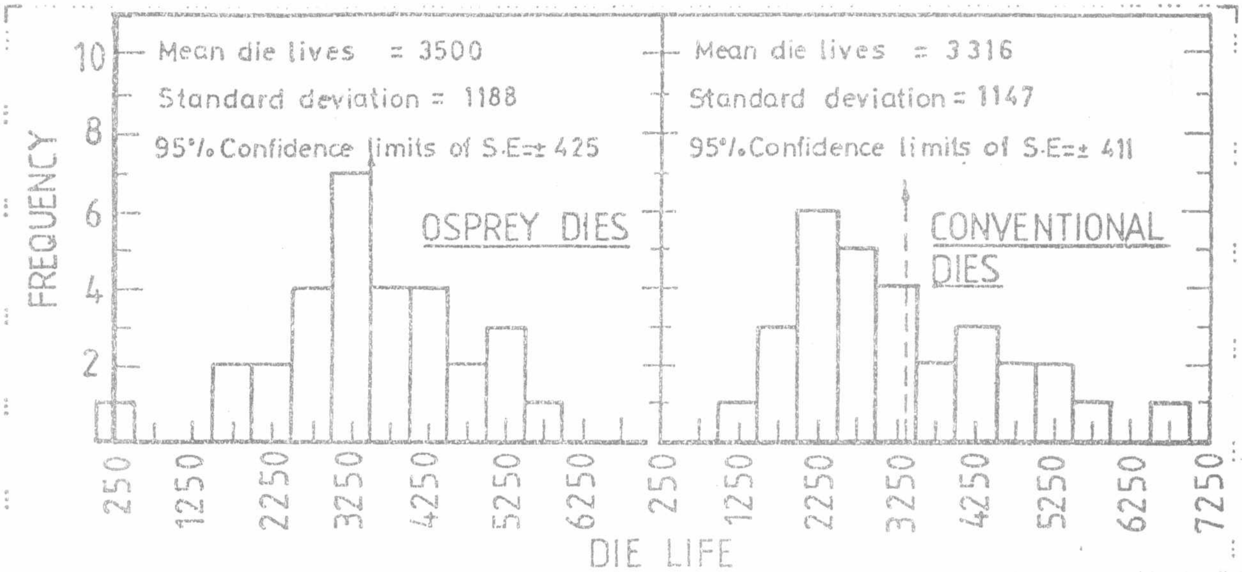



Fig. 8. Distribution of die lives for both Osprey and conventional dies.

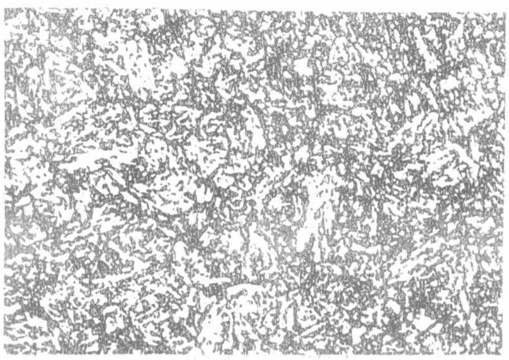


Fig. 9a. Osprey H13 die x 800

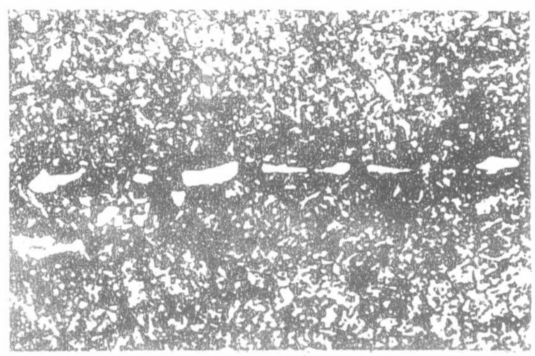


Fig. 9b. Conventional H13 die x 800

Fig. 9. General form of structure of both Osprey and conventional H13 die.

In order to evaluate Osprey process, two dies manufactured by Osprey and conventional methods which had produced 5750 forgings were chosen for metallurgical examinations. The Osprey die revealed a good nitride coating of 80 depth as shown in Fig. 10a. Metallurgically the structure of both Osprey and conventional dies was fairly the same with uniform structure of carbide in a structureless ground mass of martensite as shown in Fig. 10b and 10c respectively. The micro examination would suggest that due to excessive pressure around the flash area, the surface moved, disturbing the nitriding coating, and leading to a surface crack as shown in Fig. 10. However, the surface crack of Osprey die was less severe than that of conventional die stock. This may be explained due to the fact that the carbide segregation, which is generally existing in conventional die steel was disappeared in the case of Osprey H13. The effect of carbide segregation on the conventional die can be seen in the fracture surface also as multi steps fracture which is shown in Fig. 11a. However, there was no evidence of any segregation on the fracture surface of Osprey die as shown in Fig. 11b and most of the fracture facets have been identified as cleavage fracture with river patterns and many quasi-cleavage facets are visible. A few elongated dimples are present the bright tilted facets may be a grain boundary or a tear ridge.

X 100 X 400 X 400

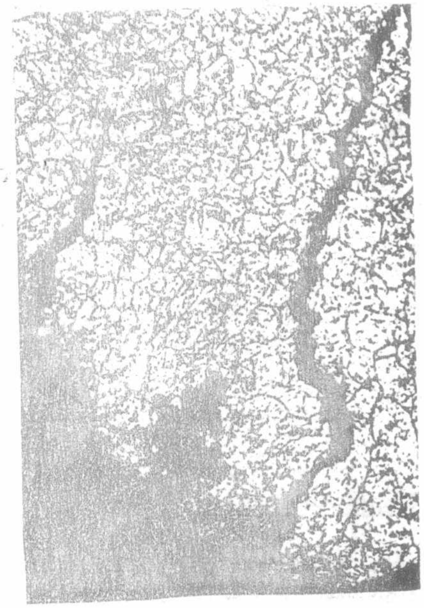
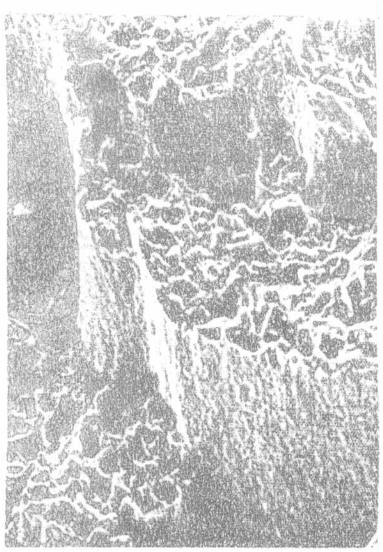


Fig. 10a. Nitriding depth Fig. 10b. Osprey H13 Fig. 10c. Conventional

Fig. 10. Microstructure examination of both Osprey and conventional dies.

Table 1 shows that the mechanical properties of Osprey H13 die are very similar to the conventional die but in the case of Osprey die the properties are isotropic. It is important to note that the impact strength for the Osprey die is normal which indicate a clean material containing no residual porosity or segregation.



Fib. 11a. Conventional H13 X 400 Fig. 11b. Osprey H13 X 400

Fig. 11. Fracture mode of both conventional and Osprey dies.

Table 1. Mechanical properties of Osprey and conventional H13.

| Properity | Osprey Isotropic | Conventional | |
|---|---|---|---|
| | | Longitudinal | Transverse |
| U.T.S. MPa. | 1689 | 1730 | 1513 |
| Y.S. MPa | 1544 | 1621 | 1327 |
| Elongation % | 9 | 7 | 4 |
| Charpy J | 68.6 | 58.8 | 29.4 |

## Cost Analysis

The preform cost of producing dies on 400 kg/hr melting unit using Osprey process can be calculated, based on Osprey estimate in some parts according to 1983 prices as follows:

| | £ | £ |
|---|---|---|
| **Capital Cost** | | |
| 2 x 200 kw Generator | 24,000 | |
| 2 x 200 kg capacity Furnace | 10,000 | |
| | | 34,000 |
| **Osprey unit** | | |
| Tundish | 10,000 | |
| Spray chamber | 5,000 | |
| Robotics and handlind | 20,000 | |
| Dust extraction | 5,000 | |
| | | 40,000 |
| Gas installation and control | 4,000 | |
| Spectrometer | 18,000 | |
| Scrap processor | 10,000 | |
| Plant installation | 20,000 | |
| Forging machine (Petro-Forge) | 30,000 | |
| Annealing furnace | 10,000 | |
| | | 92,000 |
| Total capital cost | | 166,000 |
| **Fixed Costs** | | |
| Capital depreciation 15%/Annum | 24,900 | |
| Interest on capital 10%/Annum | 16,600 | |
| Direct labour 6 men | 25,000 | |
| Overheads 3 x direct labour | 75,000 | |
| | | 140,900 |

Assuming 60% operating efficiency,
80% hours/week,
48 weeks/year,
80% preform yield.

Unit production 737.28 ton/Annum

Therefore, fixed cost/tonne of preforms = 191.1 £

Preform cost/tonne (Including forging and annealing)

| | £ |
|---|---|
| Fixed cost | 191.10 |
| Electricity | 25.75 |
| Atomizing gas | 50.00 |
| Refractories | 20.00 |
| Alloying additions | 15.00 |
| Scrap material | 200.00 |
| Fuel cost | 42.00 |

Total preform cost/tonne = 543.85 £

Average cost of H13 die steel/tonne = 1045.00 £

Possible saving/tonne = 501.15 £

Therefore, the possible annual savings = 369,488 £

## CONCLUSIONS

It should be noted that the results discussed in this paper have been produced on a development unit only, using atmozing, depositing and forging conditions which have not been fully optimised. Nevertheless, the spray-forging H13 hot worked die steel have been comparable in structure, durability and treatment with the conventional die stock. Also from economics, the new process looks highly promizing and a possible large saving of 48% over existing conventional routes of producing H13 hot worked die steel can be achieved.

## ACKNOWLEDGEMENTS

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