AD-A041 731   ROYAL ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT--ETC   F/G 20/9
A REVIEW OF POTENTIAL SERVICE APPLICATIONS UTILIZING ARC PLASMA--ETC(U)
JAN 77   A R MOSS, J A SHEWARD

UNCLASSIFIED   RARDE-TR-11/76   DRIC-BR-56680   NL

1 OF 1
ADA041731

END
DATE
FILMED
8 - 77

UNLIMITED

BR56680

11/76

ADA041731

MINISTRY OF DEFENCE

ROYAL ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

RARDE TECHNICAL REPORT 11/76

A review of potential Service applications utilizing arc plasma technology

A R Moss
J A Sheward

DDC
JUL 18 1977
C

AD NO. ___
DDC FILE COPY

Fort Halstead
Kent

January
1977

UNLIMITED

MINISTRY OF DEFENCE

ROYAL ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

(9)

RARDE TECHNICAL REPORT 11/76

(14) RARDE-TR-11/76

(6)

A review of potential Service applications utilizing arc plasma technology.

(11) Jan 77

(10)
A. R. Moss
J. A. Sheward

(12) 21p.

(18) DRIC

(19) BR-56680

SUMMARY

Recent advances in high temperature chemistry and the availability of novel plasma furnace techniques, now make it possible to produce a whole new range of materials of widespread Service interest especially for explosives and powder metallurgy. Applications are described in the context of chemical origin and comparison with existing technology. Important advantages are foreseen in the availability of very high temperatures for the preparation of products of carefully controlled physical and chemical composition. In particular, the availability of a wide range of distilled powders having a very high specific surface and being quite different in behaviour from conventionally produced powders, would seem to offer many new development opportunities.

DDC
JUL 18 1977
C

Copyright (C) Controller, HMSO, London 1977

ACCESSION for
NTIS White Section ☑
DDC Buff Section ☐
UNANNOUNCED ☐
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

310 500

CONTENTS

1. INTRODUCTION

In modern weapon development there are an increasing number of items which require special materials. These include optical, infra red and electronic devices, projectile and rocket components and also propellant and explosive fillings. Very often conventional production methods are not suitable for these special materials and novel manufacturing and processing techniques are required. The items involved may be broadly divided into two groups: those requiring intense momentary localised heating of part of some larger body, and those requiring continuous high temperature processing of bodies under controlled conditions for a predetermined period where stringent temperature and purity criteria have to be satisfied. The first group including a wide range of engineering fabrication applications such as welding are considered briefly below(1), whilst the latter, which usually require a furnace of some kind, are only now becoming feasible due to advances in high temperature technology.

2. LOCALISED HEATING APPLICATIONS

The cutting, welding, spraying and surface hardening of a wide range of materials both metallic and non-metallic may be readily carried out by a variety of high temperature processes. Equipment is now available in which the arc, glow discharge, plasma and recently the laser techniques may be used. Of these thermal methods, plasma and laser are the most versatile, producing minimum damage and contamination in surrounding material. For cutting, a high energy flux (of the order of 1 kJ/mm^2) produces intense localised heating resulting in material removal by a number of mechanisms which may involve melting, vaporisation, pyrolysis and/or chemical reaction in the plasma state.

A quantitative theory relating possible cutting speeds to power input for a wide range of materials has been published (2)(3), and it postulates chemical cutting mechanisms in addition to the processes of melting, vaporisation and pyrolysis. When certain organic materials are plasma cut, the carbon residue produced initially by pyrolysis reacts with both hydrogen plasma and nitrogen plasma thereby augmenting the cutting action of the plasma jet.

Other organic materials do not seem to undergo initial pyrolysis, but vaporise immediately and undergo a homogeneous gas phase reaction. An important feature of this work has been the ability to determine the mechanism energies for a wide range of non-metallic materials and it has been shown that this could form the basis of a comprehensive guide to likely cutting speeds and modus operandi.

3. GENERAL HEATING APPLICATIONS

A useful technique in studying the high temperature chemistry of condensed phase materials in plasma, is to entrain a stream of finely divided material within a plasma jet produced by an arc or RF discharge. The reaction products are then quenched and collected. This entrainment technique has been used for a wide range of applications including the preparation of various powders, the spraying of refractory materials in the manufacture of tungsten rocket nozzles, the growing of large single crystals and the preparation of pure boron(4). The entrainment technique is, however, of limited application because of the indeterminate residence time of the entrained particle in the high temperature zone of the plasma jet and because it has been shown that heat losses by radiation from small particles may be large under these conditions(5).

For the applications described subsequently, which require prolonged heating in the temperature range above 1500 K in a variety of chemical environments, it is necessary that new furnace techniques be developed. These techniques are described in Section 5. The applications themselves are divided into three groups associated with solids, liquids and vapours respectively and each group is sub-divided into areas of scientific/technological application.

3.1 Solids

3.1.1 Purification

Certain materials which are difficult to purify have been processed by the entrainment technique using an inert plasma stream to evaporate impurities. In RARDE boron has been processed for nuclear purposes as a moderator by upgrading from 92% to 98% purity. Further purification could be achieved by repeating the treatment. Other applications involve the removal of oxide and/or nitride films from refractory and reactive metal powders. Process efficiencies should be improved dramatically by the application of new furnace techniques which give longer reaction times.

3.1.2 Decomposition

In mineralogy, complex intractable ores may often be resolved into simple mixtures by appropriate high temperature treatment. Examples of commercial interest include rhodonite → manganese oxides + silica, ilmenite → titania + iron oxides, beryl → beryllia, alumina + silica, euxenite → uranium dioxide + titania and zircon sand → zirconia + silica. The latter 'fuse quench' process, produces zirconia from a leachable glass(6). Very recently, a 'new' process for the manufacture of molybdenum by decomposing molybdenite MoS_2 in a plasma furnace has been announced(7). The method was first demonstrated in 1964(8).

Military applications could involve decomposition of a complex in situ, perhaps in certain fabrication techniques, eg in the production of military stores by a casting process, burnt-on slag deposits could be made easily removable. Another important application is the safe disposal of chemical and biological weapons by reaction with plasma.

3.1.3 Reduction

In addition to the decomposition method described above(7), it is possible to reduce to the metal certain unreactive oxides and sulphides with carbon or hydrogen if sufficiently high temperatures are employed. Pyrophoric metal powders (iron and tungsten) have been produced by injecting oxide particles into a plasma(9). Alternatively some refractory metals may be readily obtained in a high state of purity by first converting the oxide to a volatile halide by treatment with carbon and a halogen: $MO + C + X_2 \rightarrow MX_2\uparrow + CO$ and then pyrolysing the halide usually on a hot wire.

3.1.4 Carbon and carbides

An important aspect of plasmic heating sources is that carbon need not be present. There are, however, applications where a hydrocarbon gas is added to a nominally inert atmosphere to achieve deoxidation, carburization, or to produce free pyrolytic carbon as a coating or powder. The technique has been used by RARDE to make high purity carbides. Other related applications concern the manufacture of fibre materials by plasmic pyrolysis and the potential use of certain carbides, especially boron and silicon, both as potential armour and as armour defeating materials.

3.1.5 Nitrides

These are obtained by reacting finely divided materials in nitrogen plasma. Yields over 50% have been obtained for certain metals by the entrainment technique but further improvement may be expected. Plasma produced aluminium nitride has been considered as a source of isotopes for the carbon dating technique. Currently ERDE are developing for RARDE improved igniferrous compositions to be used in an existing type of stab initiated igniter. Metal powders are incorporated in these compositions to improve the igniting power(10). The presence of metal powders, however, causes enhanced electrostatic sensitivity, which might be reduced by isolating the metal particles from the composition by means of a suitable thin coating. A nitride layer might be suitable for this purpose; it could be readily obtained by reacting the metal powder with nitrogen plasma under controlled conditions. Since the metal nitride coatings are endothermic, they would not be expected to have a detrimental effect on the igniting power of the compositions (see Section 3.3.1). The use of glow discharge plasma for nitriding a wide range of materials has been known for many years(11); recently, however, commercial equipment for continuous processing has become available in Germany(12). This process appears to offer advantages over conventional gas nitriding and salt bath methods and might supplement RARDE's existing plasma techniques.

3.1.6 Borides, sulphides, silicides etc

A vast range of compounds may be synthesised at high temperatures by reacting a metal (or metalloid) with a volatile hydride or halide; for example borides may be synthesised by the reaction $3M + 2BX_3 \rightarrow M_3B_2 + 3X_2$. Such compounds might replace tungsten carbide in armour piercing shells and could also feature in the fabrication of improved components for rockets (nose cones and nozzles), armour plate, gun liners and rocket launchers. An important advantage for certain applications may be the ability to synthesize a required compound in situ (eg on a nose cone) thus minimising contamination and giving enhanced adherance. Another possible application is in the manufacture of shells having controlled fragmentation characteristics by powder metallurgical techniques. These shells could also utilize for example oxides and nitrides.

3.2 Liquids

Although liquids by themselves are not seen as having many direct applications, they can be used in novel fabrication techniques and as a source of a whole range of important products:

3.2.1 Fabrication

In discussions with Barr and Stroud, various techniques for the fabrication of infra red materials and the construction of components including lenses for missile guidance systems were considered(13). A casting technique would involve the melting of several pounds of alumina and associated melt containment and handling problems. The generation and containment of liquid alumina and other high melting point liquids is possible within the liquid wall furnace described in Section 5. A centrifugal plasma furnace rotating about a vertical axis has been reported recently for the continuous melting of refractories such as alumina(14). A hot pressing technique which might also be used to fabricate silicon-germanium lenses, would require the use of spheroidised particles. These are also made from liquids and are discussed separately in Section 3.2.4.

3.2.2 Crystals

In optical and electronic devices crystals play an important role and modification of the well known Vernueil method is difficult for certain materials. This is principally because the flames available (oxy-hydrogen in the Verneuil method) produce unacceptable chemical changes in the molten material, either by reduction with carbon or hydrogen (ferrite crystals are easily reduced) or by carbide formation. It would seem that the use of inert gas plasma jets could obviate these difficulties and would offer the additional advantage of having an independently controllable enthalpy (heat content), which in flames is a function of the flow rates employed. It is possible to make alumina crystals several cm long in a plasma furnace(15).

3.2.3 Amorphous materials

The Science Research Council has recently highlighted the special importance of amorphous materials and the lack of technical expertise in their manufacture and fabrication(16). These amorphous materials are needed for new developments in solid state electronics (eg ovonic devices) and glasses(17), and might be of value in insulants and explosives.

Recently there has been interest in so called glassy metals(18). These are usually alloys which are cooled so rapidly from the molten or vapour state that crystallisation does not have time to occur and they have a metastable structure analogous to glass. One method used to prepare these materials is closely allied to conventional plasma spraying. This raises the possibility that some plasma sprayed coatings contain significant quantities of amorphous materials and may thus explain their unexpectedly superior properties especially ductility and resistance to thermal shock. Further work would be required to establish the validity of this hypothesis.

It is however the association of tensile strength with ductility which makes glassy metals of great potential importance. Prospective Service applications include high strength wires for incorporation in armour piercing cores, ablation resisting composites and extra tough components for fighting vehicles.

3.2.4 Spheroidised materials

These are generally made by dispensing molten material fed from a crucible into a high velocity gas stream. Refractory and reactive materials such as titanium present a problem in that there is no suitable solid crucible material available for the high temperature liquid, but this could be solved by using a plasma furnace technique (see Section 5). Spheroidised materials are of special interest in nuclear technology where it is essential to obtain a constant packing density corresponding to a given particle cross section. Spheroidised uranium carbide both pure and mixed with carbides of zirconium and thorium from a high intensity arc furnace has been examined as a nuclear fuel.

There is an interest in spheroidised materials from several points of view:- they show exceptional free flowing properties down to remarkably low particle diameters, the specific surface (m^2/kg) is minimal for a given particle size so there is minimum impurity level associated with particle surface contamination and most importantly the bulk density of these materials is higher than with other particle shapes. This last feature is of importance in certain explosive and propellant compositions. Tests have shown that it is often possible to make intractable powders free flowing by a small addition of spheroidised or other materials and 'Gasil' (a finely divided silica) has been used by RARDE to make strontium nitrate free flowing for pyrotechnics. Such procedures are thus of value in incorporating poor-flowing powdered materials into explosive or other compositions.

3.3 Vapours

These applications are mainly associated with the evaporation of solids and liquids. Homogeneous gas phase reactions followed by quenching give finely divided solid products which frequently exhibit unique properties. Such condensation processes may result in the deposition of a single compound or in the co-deposition of mixed products.

The preparation of finely divided pure materials by high temperature methods is one of the projects recently recommended by the Science Research Council for major research effort(19). The distillation of refractory materials has already yielded products of commercial interest, eg titanium dioxide pigment and silicon for the Xerox process. Service applications include uncontaminated finely divided materials in various size ranges and particle shapes for explosive and propellant compositions. There are further applications in the preparation of fillers for paints, plastics and rubbers.

3.3.1 Metals

Metal powders, especially aluminium, are frequently incorporated in high explosive compositions to increase the heat of explosion thus modifying the blast characteristic. It is important that the aluminium powder should react as soon as possible with the detonation products of the explosive. This implies that to minimise any reaction time lag it would be advantageous to increase the surface area of the metal powder in contact with the explosive, that is the specific surface of the powder (m^2/g) and particle shape factor(20) are the overriding criteria. The hypothesis is supported by work carried out by RARDE and others, which show that oxide-free blown spheroidal powders, (especially magnesium) are rather less reactive than powders produced mechanically(21). It has now been shown that powders produced by distillation have a higher specific surface than either of these and could thus be even more reactive in high explosive compositions.

Another factor to be considered is that most commercially available metal powders contain significant quantities of contaminants especially surface oxides, although aluminium and magnesium blown powders can be produced oxide free. If each metal particle is encased in a protective oxide layer, this will act as a barrier between the underlying metal and other components of the explosive composition. Whilst making for safer handling (no pyrophoricity), such a barrier could retard ignition of the metal and reduce the rate of combustion after ignition has started. Another complication with some metals (eg magnesium) is the presence of appreciable quantities of nitride in some commercially available materials. It would seem therefore that the use of uncontaminated metal powders (oxide and nitride free) would be advantageous for certain explosive compositions. There is a military interest in readily combustible aluminium alloy powders containing possibly zirconium or magnesium and in pyrophoric metals for flares and missile tracers. Explosive compositions having precise electrical conductivities covering a wide predetermined range could be formulated by using various powders made by vaporization and atomizing techniques.

Finely divided metals and alloys are also required for powder metallurgy where it is important that the materials should be free flowing and have a specified particle size distribution. The question of particle shape requires further investigation. Plasma cleaning might be used to purify cheap commercial metal powders. There is evidence that some finely divided metals may spontaneously sinter at ambient temperatures if prepared in a sufficiently uncontaminated state. Usually, finely divided air blown metal powders are too heavily oxidised for this to occur, but it could be a problem with clean plasma produced powders. Self sintering might be prevented by deactivating the particle surfaces with adsorbed inert gas or by the formation of a film of nitride, sulphide, carbide, boride etc. In the development of new alloys for armour piercing cores, there is a requirement for coated powders of tungsten and other heavy metals. This coating requirement includes cobalt, iron, copper, chromium, nickel and molybdenum.

In general endothermic compounds (ie those requiring an energy input for their formation) are readily formed at high temperatures, but tend to decompose if the temperature is reduced fairly slowly. Hence they are usually quenched to ambient temperature where the velocity of the dissociation reaction is negligible (eg nitric oxide). Hence it may be feasible to produce finely divided materials for explosive purposes which are protected by a thin film of some endothermic compound, which because it is endothermic contributes its energy of dissociation when the particle reacts on combustion. Nitrides are of special importance for this purpose, while an oxide film on the other hand would absorb energy under these circumstances. Such materials are also of interest for the newer types of dispersion hardened alloys possibly for gas turbine blades. The role of arc plasma in metallurgy is discussed in (8) and (22).

3.3.2 Oxides

ERDE have assessed many oxide based materials as burning rate catalysts to accelerate and stabilize the combustion of ammonium perchlorate propellants. Samples of titania, silica, alumina and ferric oxide have been supplied by RARDE and were prepared by using the liquid wall furnace described in Section 5(23). Alumina and silica have been produced by heating composite cores containing a stoichiometric mixture of coarse oxide powder and petroleum coke flour to produce volatile suboxides:

$$Al_2O_3 + 2C \rightarrow Al_2O + 2CO$$

$$SiO_2 + C \rightarrow SiO + CO$$

These products are not stable in the condensed phase and disproportion to give an intimate mixture of the element and higher oxide. Such a mixture of aluminium and aluminium oxide is usually pyrophoric and therefore these metastable products might be used in explosive initiators triggered by atmospheric exposure. For the preparation of finely divided oxides, however, the vapours emerging from the furnace are oxidised by quenching with air and the solid product collected in a bag filter. Batch quantities of the order of 100 g can be readily produced by this method in about 15 minutes. It is possible to distil the oxides alone, but the energy requirement in kWh/kg is very much higher. In general, particles produced by the distillation technique have a higher surface area per unit mass (specific surface m^2/g) than can easily be obtained by other methods. Measurements of the specific surface of distilled materials have been carried out by RARDE using a Micromeritics Surface Analyser Model 2200 which utilizes the BET nitrogen adsorption technique. These measurements on submicron powders have proved to be remarkably consistent and are not only much easier to carry out than particle size distribution determinations, but for many applications the specific surface of the powder is the more useful parameter.

The specific surface of these products depends on the quench conditions employed to condense them, but is usually above 100 m^2/g. To date the maximum surface area achieved for alumina has been 118 m^2/g which corresponds to a mean particle size of 140Å. For silica the corresponding values are 252 m^2/g and 110Å. These products usually appear to be made up of minute crystallites agglomerated in long chains or more complex structures which may contain crystallites down to about 15Å, each consisting of only about 150 to 200 molecules(24). As noted above there is evidence that the nature and composition of the products obtained may be altered considerably by changing the quenching rate.

The distillation method of oxide production is largely limited to those elements forming volatile suboxides and so a modification of the entrainment technique has been devised for materials such as ferric oxide. In this modification, the rate of radiant heat loss from the entrained stream of particles in the plasma is reduced by passing the stream along the axis of a rotating zirconia core at 3000 K. Under these conditions the molten ferric oxide particles are broken down and the finely divided product may be subsequently cooled and collected.

Vaporised alumina and silica have shown promise in the field of heterogeneous catalysis especially since unusual crystal phase components are present (see Section 4). Many other potential applications include tribology where the development of composites for bearings and brakes requires novel materials, and powders for the electrostatic and detonation coating processes.

4. POWDER PRODUCTION

In order to assess the viability of any new process, the total costs both capital and operating need to be evaluated. The capital costs for most plasma processes are not usually significant in the context of making comparisons with conventional processes for two reasons: they involve only readily comparable items such as power generating and control equipments, electrodes and pumps; secondly in many processes such as powder production, the major capital outlay is associated with collection and handling equipment which is required irrespective of whether plasma is used or not.

A number of large scale plasma processes using cheap materials have been costed (eg nitrogen fixation). These usually involve a high temperature stage followed by rapid quenching and product recovery. The yields are usually relatively low (about 5%), but recirculation of unused reactants is often possible and so the overriding operating cost is the energy requirement per product yield usually expressed as kWh/kg. Efficient waste heat utilization is necessary to make these processes viable(25).

The production of high cost powders and related products is quite a different proposition however, because the power costs are negligible compared with the intrinsically high material costs. The plasma process can only be justified therefore if it produces a novel product under reproducible conditions. A relevant example is the production of metal powders for explosive compositions.

RARDE had an industrial development contract to produce tonnage quantities of certain metal powders by blowing (atomizing) liquid metal in a stream of air (for aluminium) or argon (for magnesium)(26). The aluminium powders produced were oxidised and showed no pyrophoric behaviour. The magnesium powders were deliberately part oxidised (3.8% MgO) by introducing 0.1 to 2.5% oxygen into the collecting duct atmosphere thus avoiding the formation of pyrophoric blown powder. Despite this treatment, small quantities of pyrophoric materials were produced. As the vapour pressure of magnesium even close to the melting point is appreciable, it seems likely that this was due to condensation of vapour.

The powders produced were generally spherical in shape, free flowing and the plant was operated to produce a particle size of approximately 10-60µm. Various size range fractions were collected in cyclones but finally a felt bag collection system was installed to enable more of the fines to be collected. A filter of this type is incorporated in the RARDE experimental plant described in Section 5 and shown in Figure 1.

Metal and metal oxide powders produced by quenching vapours from the various arc plasma furnaces are quite different from the near spheroidal blown powders made from liquids mentioned above (see Sections 3.3.1, 3.3.2). The particle shape is often indeterminate and these products usually consist of complex agglomerates of tiny crystallites. They are characterised by high specific surface. In addition some materials will be deposited in a different allotropic modification, (usually crystal structure) to those from the liquid state and will in general have the lowest possible heat of formation and may be metastable. Examples are the preparation of a mixture of γ and δ alumina by distillation(15) and amorphous materials(18).

5. HIGH TEMPERATURE TECHNOLOGY

During the past decade there has been a breakthrough in the development of high temperature generators or plasma devices as they are now being called. Much of the work especially for chemical applications has been carried out secretly by commercial interests and usually involves the development of a plasma furnace of some kind. The word furnace is used here in a much more generalised sense than usual to mean a fixed enclosed volume which may be either raised to a given high temperature or more usually, in which a given high rate of energy release is associated with a given rate of reactant throughout for an extended period of time.

Unconstricted flames or plasma jets may not properly be regarded as furnaces, since their boundaries are not clearly defined and often show cyclic instability. Consequently, in the processing of finely divided materials by these means (the entrainment technique described in Section 3) there is no certainty that reactants will actually pass through the hot zone. There is a further difficulty in passing material through the viscous and usually turbulent boundary layer around the plasma particularly for plasma jets.

There are two factors which make plasma furnaces of supreme importance for the melting, vaporisation and reaction of materials. Firstly, the power input/furnace volume ratio may be so high that all materials can be melted and vaporised and the equilibrium temperature of the plasma produced may easily reach 10,000 K. Secondly, the desired operations may be performed over a wider range of chemical and pressure conditions than hitherto, when high temperature chemistry was complicated by the presence of combustion or reduction products.

The melting and evaporation of many materials, especially metals, may be carried out under chosen conditions including completely inert environments. An extensive range of compounds may be synthesized at high temperatures for the applications previously discussed. The variety of envisaged applications described suggests that several types of furnace need to be considered in order to meet requirements. External views of two furnaces developed by RARDE are shown in Figure 1.

For the prolonged heating of solids and liquids, particularly where stringent temperature and purity criteria have to be met, the liquid wall plasma furnace offers considerable promise(15). It consists essentially of a suitable thick walled horizontal ceramic tube or core rotated axially and melted from the inside by a plasma jet, so that the liquid layer or layers obtained are held centrifugally against the core wall. The core itself is held inside a water cooled steel sleeve within the furnace and driven at about 600 rpm by a variable speed motor unit. The sleeve is closed at each end by two stationary flanges, one of which supports the plasma torch whilst reaction products are quenched at the other end and passed along a cooled tube usually to a bag filter unit.

As an example of its use aluminium metal may be easily melted and evaporated from an alumina core since liquid aluminium is less dense than molten alumina and floats on it. For denser materials such as titanium it is necessary to use other core materials such as zirconia or thoria. The use of cores containing carbon for the production of distilled oxides by making use of the formation of volatile suboxides has already been described. In this and many other applications the great advantages are: continuous operation (several hours if need be), high efficiency and minimal radiation losses. A modification uses an arc transferred to the inside of a conducting core for the melting or evaporation of very refractory materials. A furnace of this type which is rotated about a vertical axis has been reported (14).

The original cold wall rotating plasma furnace is shown in a RARDE film entitled 'Arc Plasma Technology'(27). A vertical arc column is expanded by viscous drag forces generated by means of a coaxial rotating cylinder usually of quartz to produce a ball of plasma. In a new furnace of this type built by RARDE, the electrodes are replaced by plasma jets to minimise erosion losses. Expanded plasma fireballs over 2 litres in volume have been obtained at 100 kW arc power (Figure 2). More advanced versions of this furnace should provide a higher power density than is obtainable by other methods. The high temperature plasma zone (fireball) within this type of furnace is independent of any surrounding solid or liquid container, which although making for much greater versatility in chemical systems that may be utilized, does result in high radiative energy losses particularly if particles are present in the plasma.

Aluminium powder of 150μm mean particle size has been evaporated within the cold wall rotating plasma furnace using a low powder feed rate. The vapour was quenched within the furnace to form a finely divided product as it was carried beyond the plasma fireball by convective gas circulation. Small powder samples were subsequently recovered from cooler parts of the furnace. When attempts were made to withdraw reaction products continuously from the furnace arc instability was encountered. This instability seemed to be associated with deionization enhanced by a high radiative energy loss from evaporating particles in the plasma.

As indicated previously (Section 4), the nature of the products obtained by condensing vapour from a plasma will often depend on the quenching rate of the system. In RARDE a large hyperbaric chamber capable of operating up to 7 MPa, under wet or dry conditions, could be used to study the effects of the high quenching rates associated with these pressures(28).

In addition to these two furnaces (centrifugal liquid wall and cold wall rotating plasma) many other plasma devices have been developed for chemical processing(29). A large arc heater for powders (particle size >20μm) having a claimed throughput of 1 kg/min was described recently(30).

6. CONCLUSIONS

1. A wide range of Service applications of high temperature materials science and technology have been described, for which arc plasma devices have a great potential.

2. Furnace techniques are envisaged which will permit the melting, vaporisation and reaction of many metallic and non-metallic materials.

3. Glove box techniques are necessary when handling some of the products mentioned to minimise contamination and to provide safe working conditions especially with pyrophoric or toxic materials.

7. RECOMMENDATIONS

It is recommended that the applications described be used to formulate a continuing programme of high temperature development aimed at the anticipated Service requirements.

8. REFERENCES

1. A R Moss, New Technology 1967, 9.
2. A R Moss, J A Sheward, RARDE Memo 2/71.
3. A R Moss, J A Sheward, IEE Conference 'Electrical Methods of Machining, Forming and Coating' (1970) Paper 41 'The Arc Plasma Cutting of Non-Metallic Materials'.
4. A R Moss, Inst of Welding 1963 'Arc Plasma Technology'
5. R L Brown et al, J Inst Fuel 1968, Nov 433-9.
6. M L Thorpe, Eng and Mining J 1971, 'Is there a bright future in store for high-temperature technology in mining'?
7. W H Gauvin Conference 'Plasma Processing of Materials' Society of Chem Industry, Polytechnic of the South Bank, London Sept 1974
8. A R Moss, W J Young Powder Met Inst of Metals 1964, 7 (14) 261.

9. C S Stokes et al 'Plasma Jet Chemistry' AFOSR-62-196 (Final rept) 1964

10. K J Holloway, Ministry of Defence unpublished report.

11. H Bennek, O Rudiger, Archiv das Eisenhuttenwesen 1944/45, 18, (3/4), 61-67.

12. T J Bewley, Metallurgia and Metal Forming 1974, 41, (8), 227-229.

13. Letter from Barr and Stroud 24.11.71.

14. F H Howie, I G Sayce, Rev int Htes. Temp et Refract 1974, 11, 169-176.

15. B Selton, J A Sheward, J Materials Science 1969, 4, 302-9.

16. Science Research Council 'The Physics of Amorphous Materials' 1970.

17. D Adler Electronics, 1970, Sept 28, 61-72.

18. A L Robinson, Science 1973, 182, 908-910.

19. Science Research Council 'High Temperature Processes' 1971.

20. T Allen 'Particle Size Measurement' Chapman and Hall 1968.

21. Committee on Manufacture and Use of Tracer Compositions in Small Arms Ammunition RSAF, Design and Development Section Enfield, Unpublished Ministry of Defence Committee Minutes.

22. A R Moss Proc 17th Annual SCRATA Conference, Harrogate 1971. 'Arc Plasma Technology in the Steel Castings Industry'.

23. Letter from G Spickernell ERDE 16.12.71.

24. Conference 'Plasma Physics in Chemical Synthesis' Electricity Council Research Centre Capenhurst 1970.

25. BP 890, 414 ICI 1958.

26. Contractors Report from Metals and Alloys (Birmingham) Limited Mar 1972.

27. J Pullen, The Engineer 589-91 October 21, 1966.

28. A R Moss, W J Young 'A Deep Water Simulator for Arc Plasma Investigations' Seminar 'Underwater Welding for Offshore Installations' London 1976.

29. I G Sayce, 'Heat and Mass Transfer in Thermal Plasmas' IUPAC Round Table Odello, France 1975.

30. Meeting Electrochem Tech Group Soc of Chem Ind 'Plasma Heat Transfer and Measuring Techniques' Herior-Watt University of Edinburgh, 8/4/76.

FIG. I

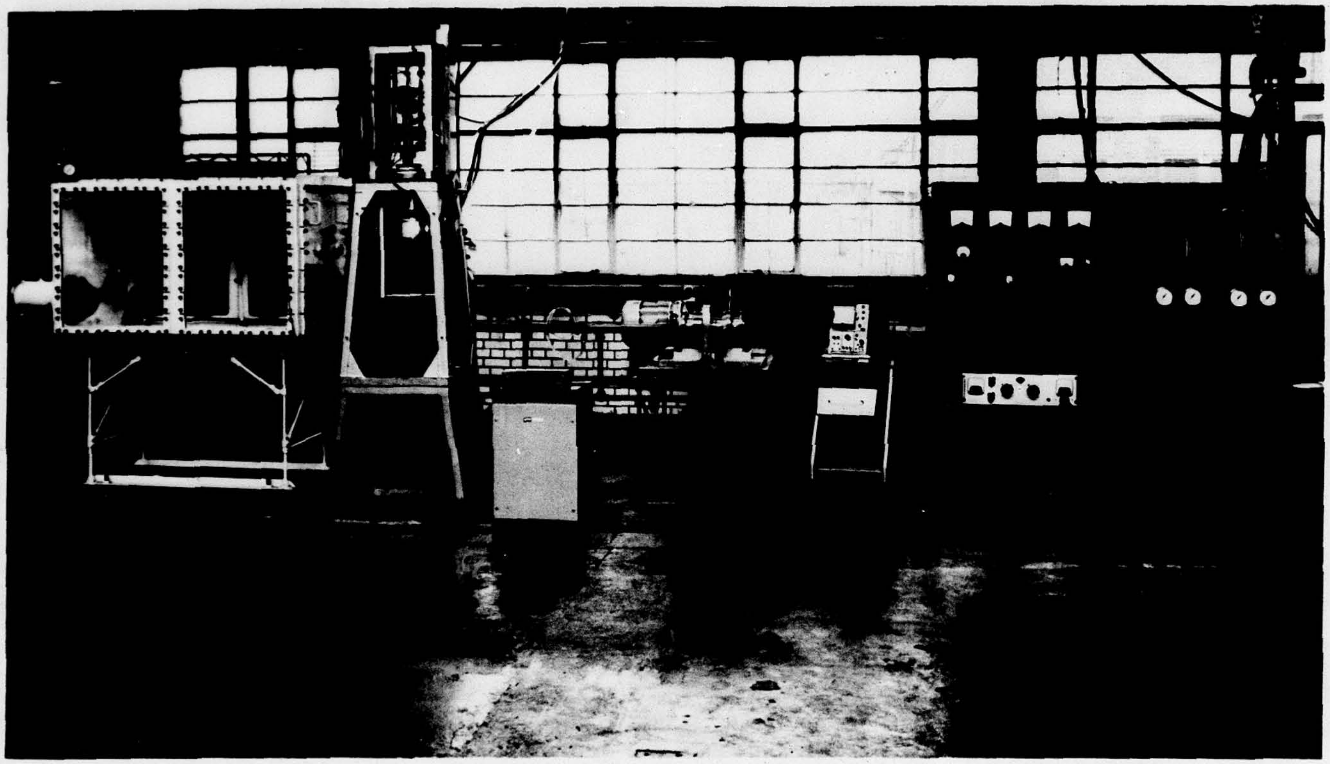

FIG. 1 RARDE's EXPERIMENTAL PLASMA FACILITY FOR THE PRODUCTION AND HANDLING OF POWDERS. FROM RIGHT TO LEFT: CONTROL PANEL, LIQUID WALL FURNACE WITH QUENCHING TUBE, BAG FILTER UNIT, COLD WALL ROTATING PLASMA FURNACE AND GLOVE BOX

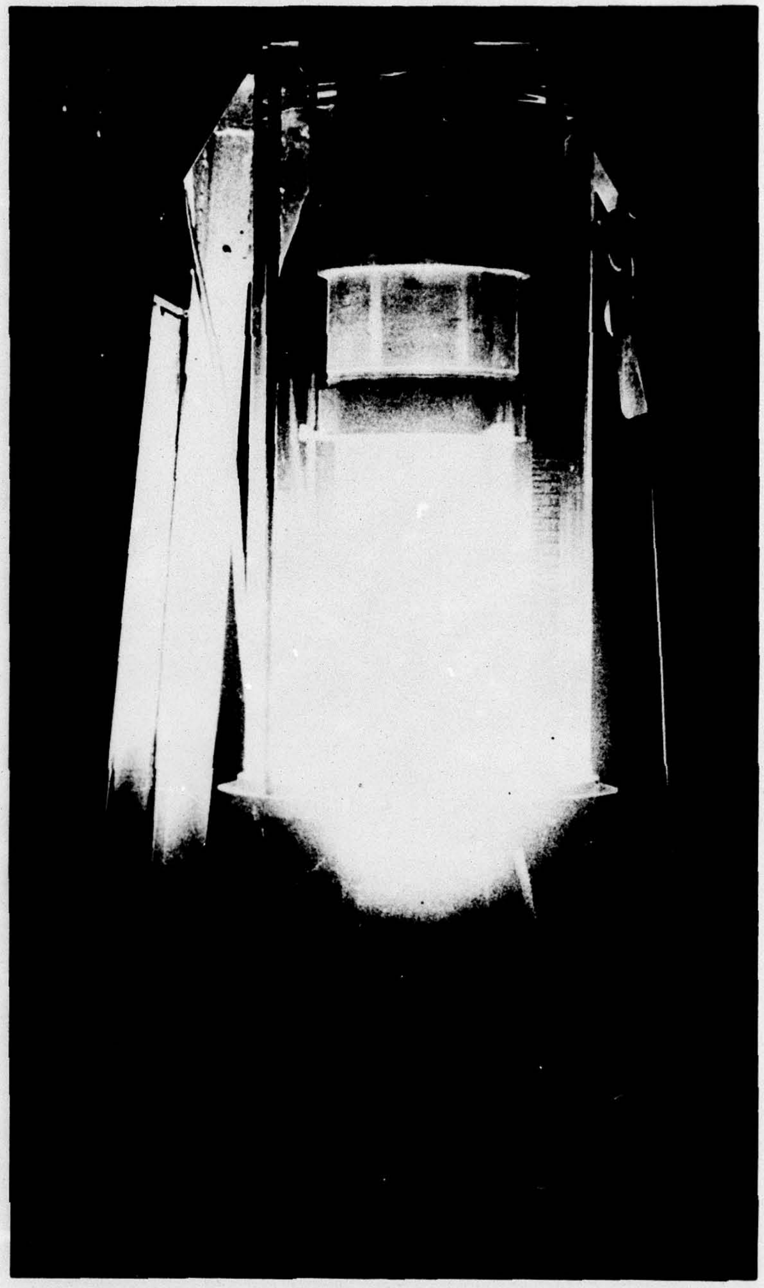

FIG. 2 COLD WALL ROTATING PLASMA FURNACE SHOWING A PLASMA FIREBALL

DOCUMENT CONTROL SHEET

(Notes on completion overleaf)

Overall security classification of sheet ....UNLIMITED..

(As far as possible this sheet should contain only unclassified information. If is is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R),(C) or (S)).

1. DRIC Reference (if known)	2. Originator's Reference RARDE TECHNICAL REPORT 11/76	3. Agency Reference	4. Report Security Classification UNLIMITED

5. Originator's Code (if known) 851600	6. Originator (Corporate Author) Name and Location Royal Armament Research & Development Establishment Ministry of Defence UK
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location

7. Title

A review of potential Service applications utilizing arc plasma technology.

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers). Title, place and date of conference

8. Author 1. Surname, initials	9a Author 2	9b Authors 3, 4...	10. Date	pp	ref
Moss, A R	Sheward J A		1.77	16	30
11. Contract Number	12. Period	13. Project	14. Other References		

15. Distribution statement

No limitations

15. Descriptors (or keywords)

Plasma jets
Plasma devices
Plasma generators
Powder (particles)
Refractories
Refractory materials
Chemical reactions (TEST)

continue on separate piece of paper if necessary

Abstract

Recent advances in high temperature chemistry and the availability of novel plasma furnace techniques, now make it possible to produce a whole new range of materials of widespread Service interest especially for explosives and powder metallurgy. Applications are described in the context of chemical origin and comparison with existing technology. Important advantages are foreseen in the availability of very high temperatures for the preparation of products of carefully controlled physical and chemical composition. In particular, the availability of a wide range of distilled powders having a very high specific surface and being quite different in behaviour from conventionally produced powders, would seem to offer many new development opportunities.

NOTES ON COMPLETION OF DOCUMENT CONTROL SHEET

This Document Process Sheet is designed specifically for MOD reports and reports produced by Contractors.

Boxes marked* need be completed only if the information is readily available.

*Box 1. DRIC reference: Enter DRIC reference (BR number) if one has been assigned.

2. Originator's Reference: Enter the report number by which the document is identified by the originator of the report, in the form in which it appears on the cover.

3. Agency reference: Enter reference number allocated by sponsoring agency (contract authority) in the case of contract reports.

4. Report Security Classification: Enter security classification or marking which limits the circulation of the report, or enter UNLIMITED when this applies.

*5. Originator's Code: Code number for the DRIC-standardised form of the entry appearing in Box 6.

*5a. Sponsoring Agency's Code: Code number for the DRIC-standardised form of the entry appearing in Box 6a.

6. Originator (corporate author): Enter name and location of the organisation preparing the report.

6a. Sponsoring Agency (Contract Authority): Enter the name of the monitoring MOD Branch or Establishment in the case of contract reports.

7. Title: Enter the complete report title in capital letters but omitting initial definite or indefinite articles. If the report covers a specific period, enter this after the title, eg (1.1.1972-31.3.1972).

7a. Title in Foreign Language: In the case of translation, enter the foreign language title (transliterated if necessary) and the translated English title in Box. 7.

7b. Conference Papers: If 7 is the title of a paper presented at a Conference, or a Conference proceedings, enter the Conference Title, where it was held and the date.

8. Author 1: Enter the name of the first author, followed by his initials.

9a. Author 2: Enter the name of the second author, followed by his initials.

9b. Authors 3,4...: Enter third and following authors' names.

10. Date: Enter the month (in figures) and the year of the report (Dec., 1969 is written 12.1969). If the report is undated but a period covered by the report is indicated, enter the date at the end of the period.
pp.ref. Enter the inclusive number of pages in the report containing information, i.e. including appendices, tables and illustrations, and the total number of references cited.

11. Contract Number: Enter the number of the contract or grant under which the report was written.

12. Period: (always associated with the Contract Number). Only to be used for reports covering a specific period, e.g. quarterly, annual or final reports. Enter QR-1, AR, FR, as appropriate.

13. Project: Enter project name or number.

14. Other Reference: Enter any reference, other than those in Boxes 2 or 3, by which the report may be identified.

15. Distribution statement. Enter any limitations on the distribution of the document. If distribution is limited to particular groups eg MOD, MOD and its Contractors, etc. it should be stated. If the distribution is the responsibility of another authority eg a HQ Directorate, enter "responsibility of .... and name the authority.

Descriptors: Any number of descriptors (or key-words) can be entered. If selected from a published thesaurus, eg The Thesaurus of Engineering and Scientific Terms (TEST), this should be indicated.

Abstract: The abstract should preferably not exceed 150 words, i.e. it can be considerably shorter than the Abstract to be provided on the Title Page of the Report. Information available in the report title need not be included in the abstract.

Ministry of Defence
Royal Armament Research and Development Establishment
RARDE Technical Report 11/76

621.791.755:
621.791.947.55:
533.9:
541.124

A review of potential Service applications utilizing arc plasma technology
A R Moss, J A Sheward

January 1977

Recent advances in high temperature chemistry and the availability of novel plasma furnace techniques, now make it possible to produce a whole new range of materials of widespread Service interest especially for explosives and powder metallurgy. Applications are described in the context of chemical origin and comparison with existing technology. Important advantages are foreseen in the availability of very high temperatures for the preparation of products of carefully controlled physical and chemical composition. In particular, the availability of a wide range of distilled

---

Ministry of Defence
Royal Armament Research and Development Establishment
RARDE Technical Report 11/76

621.791.755:
621.791.947.55:
533.9:
541.124

A review of potential Service applications utilizing arc plasma technology
A R Moss, J A Sheward

January 1977

Recent advances in high temperature chemistry and the availability of novel plasma furnace techniques, now make it possible to produce a whole new range of materials of widespread Service interest especially for explosives and powder metallurgy. Applications are described in the context of chemical origin and comparison with existing technology. Important advantages are foreseen in the availability of very high temperatures for the preparation of products of carefully controlled physical and chemical composition. In particular, the availability of a wide range of distilled

---

Ministry of Defence
Royal Armament Research and Development Establishment
RARDE Technical Report 11/76

621.791.755:
621.791.947.55:
533.9:
541.124

A review of potential Service applications utilizing arc plasma technology
A R Moss, J A Sheward

January 1977

Recent advances in high temperature chemistry and the availability of novel plasma furnace techniques, now make it possible to produce a whole new range of materials of widespread Service interest especially for explosives and powder metallurgy. Applications are described in the context of chemical origin and comparison with existing technology. Important advantages ar- foreseen in the availability of very high temperatures for the preparation of products of carefully controlled physical and chemical composition. In particular, the availability of a wide range of distilled

---

Ministry of Defence
Royal Armament Research and Development Establishment
RARDE Technical Report 11/76

621.791.755:
621.791.947.55:
533.9:
541.124

A review of potential Service applications utilizing arc plasma technology
A R Moss, J A Sheward

January 1977

Recent advances in high temperature chemistry and the availability of novel plasma furnace techniques, now make it possible to produce a whole new range of materials of widespread Service interest especially for explosive and powder metallurgy. Applications are described in the context of chemical origin and comparison with existing technology. Important advantages are foreseen in the availability of very high temperatures for the preparation of products of carefully controlled physical and chemical composition. In particular, the availability of a wide range of distilled

For Indexing

powders having a very high specific surface and being quite different in behaviour from conventionally produced powders, would seem to offer many new development opportunities.

14 pp 2 figs - tabs 30 refs

powders having a very high specific surface and being quite different in behaviour from conventionally produced powders, would seem to offer many new development opportunities.

14 pp 2 figs - tabs 30 refs

powders having a very high specific surface and being quite different in behaviour from conventionally produced powders, would seem to offer many new development opportunities.

14 pp 2 figs - tabs 30 refs

powders having a very high specific surface and being quite different in behaviour from conventionally produced powders, would seem to offer many new development opportunities.

14 pp 2 figs - tabs 30 refs