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THE COLLEGE OF AERONAUTICS

DEPARTMENT OF MATERIALS

Research in the Department of Materials 1966/67

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The postgraduate courses of the Department of Materials are of one-year's duration and are concerned with the general principles of materials science, as related to a variety of materials, both metallic and non-metallic, and the applications of these materials in engineering at large. During the course the students undertake a project in part-fulfilment of the requirements for graduation.

In addition a number of Research Fellows are engaged in long term research in the Department, usually on research contracts from outside bodies. The research activities are necessarily more limited than those of a comparable University Department since at present it is not yet usual for students to work for a Ph.D. over two to three years.

It is convenient to divide the subjects into four groups:

i. Metallic materials;
ii. Polymeric materials;
iii. Welding metallurgy and technology;
iv. Contract research.

(i) Metallic materials.

Precipitation of Niobium Nitride in A Commercial Steel

M. Boyles (Student)
Mr. B.S. Hockenhull (Supervisor).

This process and its kinetics are not well understood. Some work is already in progress on aluminium nitride precipitation (R.T.B. Contract), and this work is attempting to follow the process by measurements of internal friction, particularly by following the Snoek peak height. The work is to include an examination of the mechanical and thermal prehistory on the ageing process. The initial preparation of specimens, setting up a 1 c/s pendulum and some ageing runs have been completed.

Rolling Recrystallisation Textures of Commercial Grades of Low Carbon Steel

T. Flavell (R.T.B. Research Fellow)

The influence of $[Al]_\alpha$ and $[N]_\alpha$ precipitation, during annealing, upon the rolling-recrystallisation texture of super-saturated, (i.e. w.r.t. $[Al]_\alpha$ and $[N]_\alpha$), cold worked ferrite is being investigated. A commercially produced aluminium killed steel (.006N, .046Al) is being used for this work. The interest stems from the observation that, in the commercial production of sheet material for presswork application, certain advantages in sheet formability are to be gained by allowing aluminium nitride to precipitate during the final anneal. Such precipitation can increase the value of

the coefficient of normal plastic anisotropy, 'r', by the formation of a texture with a relatively high proportion of {111} in the plane of the sheet.

The kinetics of AlN precipitation are being studied by internal friction while X-ray texture studies are being used to follow the resultant texture changes.

Structural Changes in Two-Phase Alloys During Hot Fatigue

Professor W.J.McG. Tegart
M.J. Luton (College Research Fellow).

Recent work at the University of Sheffield has shown that the spheroidisation of pearlite can be greatly accelerated during hot fatigue. The acceleration is comparable to that produced by severe cold work prior to annealing. It has been suggested that the acceleration is due to enhanced diffusion along the high angle sub-boundaries formed in ferrite during fatigue. Such changes should occur in other two-phase systems where lamellar structures are produced either by controlled cooling or transformation. These structures have been proposed for potentially strong material for high temperature usage and the present work aims to examine the limitations imposed on directionally solidified eutectic alloys by softening during hot fatigue.

Fatigue at 20 kc/s

H.A. Monks (Student)
Mr. B.S. Hockenhull (Supervisor)

A resonant magnetostrictive device giving a high amplitude vibration at 20 kc/s has been developed over a period in the department. This is now capable of carrying out fatigue tests on plain cylindrical rod specimens.

Most of the work so far has been concerned with several age-hardening aluminium alloys with a concentration latterly on RR58. The aim has been:

(a) To compare the high frequency fatigue properties with those at lower frequency in order to try to understand the frequency effect.

(b) To evaluate the possibility that such high frequency testing might be used for high speed evaluation of a material even though there may be no simple correlation between high and low frequency properties.

So far, σ-N curves have been produced for the materials mentioned above and it is found that (a) a frequency effect exists; (b) surface preparation has a strong effect on the high frequency properties; (c) heat treatment in the ageing alloys has an effect on the high frequency properties which is not evident at lower frequencies; (d) the fatigue limit is apparently raised at high frequency, and (e) there are probably strong environmental effects.

At the moment the evidence suggests that at high frequency the initiation stage of the fatigue process is inhibited. This inhibition may be due to the small plastic strain amplitude/cycle or to environmental factors.

The present work is a study of the effects of environment on the fatigue of RR58 at high and low frequency, using electron microscopy, optical and scanning electron microfractography.

Effect of Microstructure on the Mechanical Properties of a Eutectoid Steel

R.G. Murray (Student)
Mr. M.J. George (Supervisor)

The aim is to correlate changes in microstructural parameters, e.g. pearlite interlamellar spacing, pearlite nodule size, prior austenite grain size, with consequent changes in strength and ductility. The first two parameters are affected by transformation temperature and the third (with the possible addition of the second) by austenitizing temperature. The initial work is a study of the effect of transformation temperature after a low austenitizing temperature.

Compressive Instability in Sheet Metals

H. Naziri (Student)
Mr. R. Pearce (Supervisor)

Empirical observations of the flange-folding behaviour of anisotropic metal indicate that the strain-ratio 'r', has an important effect on this type of failure. Initially polycrystals with a range of r values, e.g. zinc, aluminium, deep drawing steel, titanium and zirconium, will be studied to determine the effects of planar and normal anisotropy on this phenomenon. Later it is proposed to study folding in a range of aluminium single crystals. Polyethylene-film lubrication will be used for this work and a preliminary study of flange drawing using this lubricant will be carried out.

Bulging of Commercial Purity Aluminium Single Crystals

J. Neville (Student)
Mr. R. Pearce (Supervisor)

The final aim is to describe the behaviour of aluminium sheet single crystals under biaxial tension in crystallographic terms and to discuss their ductility and fracture behaviour in terms of their through-thickness workhardening behaviour. Previous work by Bott and Pearce is being continued and a computer programme for analysing the results is being checked.

Reversion Behaviour of a Medium Strength Aluminium Alloy

G. Sweetsur (Student)
Mr. A.R. Sollars (Supervisor)

In the welding of medium strength aluminium alloys, reversion processes occur widely in the heat affected zones and are of particular importance in multi-cycle welding processes. A study of the literature and the results of work on heat affected zone structures carried out at Cranfield show that the explanations of reversion put forward are not satisfactory in explaining HAZ effects. Early ideas based on critical particle size and later ideas based on metastable solvus boundaries in themselves are not sufficient and, from recent models it appears that a combination of the two theories is nearer the truth.

The aim is to produce variations in precipitated structures by solution treatment, quenching at various rates followed by ageing with and without delay, with and without intermediate cold work and by direct quenching from solution temperature to ageing temperature and to subject these samples to short (up to perhaps 30 minutes) reversion treatments and to study the structures produced by thin foil techniques. It is hoped that an explanation of the effects can be based on the more recent theories. Some exploratory heat treatments have been carried out and a new apparatus for producing thin foils has been designed and built.

Stretch-Forming Behaviour of Commercial-Purity Zinc Sheet

D. Williams (Student)
Mr. R. Pearce (Supervisor)

Preliminary experiments have shown that zinc sheet ('cold' reduced approximately 80%) exhibits remarkable ductility in biaxial tension. It is well known that zinc recovers and recrystallizes at room temperature, but it is not clear whether it is the rolling process which produces a zinc sheet of enhanced drawability or whether the rate of forming is determined by recovery and/or recrystallisation or whether - as is more probable - it is an interaction of the two. It is proposed therefore to study the properties of rolled zinc in uniaxial and biaxial tension over a range of strain rates, to examine the effects observed in terms of metallographic and crystallographic properties and, finally to decide whether the Backofen interpretation of superplasticity is relevant to this behaviour.

An Investigation of Microstructural Features of Vacuum-Melted Nimonic 105 Sheet Materials After Creep

J. Wright (Student)
Mr. A.R. Sollars (Supervisor)

A programme of creep testing of this material at Lucas Gas Turbines

Ltd., Burnley, showed that intermediate ageing processes (intermediate between solution treatment and final ageing) could markedly affect the subsequent creep behaviour. It was thought that the creep strain and temperature were critical factors in altering the microstructure and that modifications to the initial microstructure by more complex heat treatments could be markedly effective in altering the creep behaviour of the alloy. A large number of microsections of as-heat treated and heat treated and creep strained samples have been made available for study, together with all the relevant creep test data. To date suitable replication techniques have been worked out and detailed studies of structures are commencing. The aim is an understanding of the reasons why quite small changes in intermediate ageing temperatures and times can have profound effects on subsequent creep behaviour.

ii. Polymeric Materials

The research in polymeric materials is being carried out under the general supervision of Professor D.W. Saunders. It can be conveniently grouped under three headings:-

Degradation and Cure in Thermosetting Resins

Mr. D.A. Smith (Lecturer)
Dr. D.P. Bishop (Research Fellow)

The mechanism of degradation of thermosetting resins is not well understood. Work is being carried out to examine the products of pyrolysis of epoxide resins at temperatures between 400 and 800°C using the techniques of gas-liquid chromatography allied with infra-red spectroscopy and radioactive tracer work. It is hoped to gain a fundamental understanding of the mode of degradation and of its variation with type of resin-hardener system.

At lower temperatures (200 - 350°C) degradation and curing have been studied by their effect on the dielectric power losses at frequencies in the range 2×10^2 to 9×10^4 c.p.s. and by examination of the degradation products appearing in suitable vacuum traps.

Work is now being initiated on the assessment of degree of cure in polyester resins.

Deformation of Elastomers

Mr. M.M. Hall (Lecturer)
Mr. M. Nash (Student)

Large deformations in elastomers are approximately described by the kinetic theory of rubber-like elasticity which predicts detailed forms for the load-deformation relations in general elastic deformations.

The detailed behaviour of real elastomers shows systematic deviations from this ideal theory, in the form of the load-deformation relations. The reasons for these departures are not well understood; in particular the role of departures from elastic reversibility, due to the time effects always encountered with these materials, is not clear. Experiments in torsion and in general pure homogeneous deformation on various elastomers have been undertaken to investigate these effects.

The kinetic theory can be extended, on the basis of some simple assumptions about the optical properties of covalent systems, to describe also the photo-elastic properties of elastomers. For the case of chemically simple elastomers e.g. cross-linked polyethylene at temperatures above its melting point, the stress-strain-birefringence properties can be used to obtain information on both conformational energies and on optical properties of single molecules. Experimental work on photo-elastic properties is in progress to examine these effects.

Orientation and Anisotropy in Thermoplastic Materials

Mr. W.J. Organ (Assistant Lecturer)
Mr. M.W. Darlington (Research Fellow)
Mr. D. Clayton (Student)
Mr. A.J. Cobbold (Student)
Mr. T.J. Mullen (Student)

Many thermoplastics materials, whether glassy or partially crystalline, are capable of displaying highly anisotropic physical properties as a result of molecular orientation due to deformation imposed either above or below the melting range of the material.

Particular effects being investigated are the effects of molecular orientation on: (a) morphological structure and texture using both x-ray and optical techniques, and (b) mechanical properties using a range of mechanical test procedures. Efforts are being made to correlate and connect the various properties being examined.

iii. Welding Metallurgy and Technology

Three of these projects are being carried out under the supervision of Mr. J.E.M. Jubb of the Department of Aircraft Design on a co-operative basis with the Department of Materials.

Heat affected zone studies in low alloy steels

This is a major programme under the supervision of Dr. R.L. Apps, an S.R.C. Research Fellow, Mr. E. Smith, and an S.R.C. Research Assistant, Mr. M.D. Coward. Two students, B.E. Blanchard and L.J. Brown are carrying out project work on this topic. Another member of staff, Mr. M.J.George, is also carrying out research in this field.

The aim of the programme is to determine the relation between the weld thermal cycle, metallurgical structure and mechanical properties (particularly notch toughness) of various regions of the weld heat affected zone in several mild and low alloy steels.

In view of the small physical size of weld heat affected zones, mechanical testing has been carried out on specimens taken through a simulated weld thermal cycle by equipment specially constructed for the purpose.

The thermal cycles that occur in the heat affected zones of $1\frac{1}{2}$ inch thick steel plate have been determined for heat inputs of 108 and 56 kilojoules/inch. Associated microstructures have been recorded.

The following steels are being investigated:

BS15 (M.D. Coward)

The weld heat affected zone has been examined metallographically. Specimens have been thermally cycled to peak temperatures of 1347°, 1070°, 893° and 788°C, both with and without imposed restraint. These specimens now await testing and examination.

BS1501-161-C (E. Smith)

The weld heat affected zone has been examined. Specimens have been thermally cycled to peak temperatures of 1347°, 1088°, 893° and 788°C, and are now awaiting testing.

QT35 (M.D. Coward)

The weld heat affected zone has been examined. Specimens have been thermally cycled to peak temperatures of 1347°, 1070°, 893° and 788°C, with and without restraint. Testing is in progress.

Ducol W30 (L.J. Brown)

The weld heat affected zone has been examined. Thermal cycling, examination and testing will be carried out.

Cr Mo Steel ($2\frac{1}{4}$ Cr, 1 Mo; $2\frac{1}{4}$ Cr, 1 Mo, 1 Nb) (B.E. Blanchard)

The effect of Nb on the heat affected zone structures will be examined and a limited amount of thermal cycling of specimens will be carried out depending on the time available.

BS 968 (Nb grain refined mild steel) (Mr. M.J. George)

A number of thermal cycles have been determined in a weld and control problems with the simulator are being investigated.

Lamellar Tearing

D. Elliott (Student)
Mr. J.E.M. Jubb (Supervisor)

Some basic work on lamellar tearing was carried out by D. Nicholls at Cranfield in the previous session and Elliott is continuing and developing the initial work which aims to provide a suitable test for susceptibility to lamellar tearing. Measurements of strains and temperatures during the welding and cooling cycle are being carried out to throw light on hypotheses which have been put forward to explain this mode of failure.

Effect of Residual Stresses on Buckling Behaviour of Welded Stiffened Panels

R. Hovey (Student)
Mr. J.E.M. Jubb (Supervisor)

The procedures for stressing stiffened panels with bending moments and shear forces are being surveyed. Stiffened panels susceptible to elastic local buckling will be tested without and with the residual stresses arising from longitudinal fillet welds. Residual stresses from welding will be measured.

The Properties of Electroslag Welds

E. Lawyer (Student)
Dr. R.L. Apps (Supervisor)

It is hoped to determine the effect of heat input upon the properties of electroslag welds in 2" thick mild steel.

This project is a continuation of work carried out in 1964-65 which indicated a marked dependence of the mechanical properties on heat input.

Fatigue Behaviour of Resistance Spot Welded Joints

V. Muthuswamy (Student)
Mr. J.E.M. Jubb (Supervisor)

In continuation of previous work in the department, the fatigue behaviour of resistance spot welded joints is being investigated to separate the variables, such as sheet indentation and separation, which occur during production conditions. The initial work is being concentrated on process control in order to produce an acceptable range of fatigue specimens. A programme for fatigue testing has been prepared.

The Development of the Weld Nugget in Resistance Spot Welding

S. Nicholson (Student)
Dr. R.L. Apps (Supervisor)

The aim is to study the growth of the weld nugget during the spot welding process and to determine the relative significance of interfacial and body resistance. The project will also probably involve instrumenting the resistance welding machine to measure secondary voltage and current.

A Metallurgical Study of Flash Welds in Stainless Steel Tubes

A.J. Summerfield (Student)
Dr. R.L. Apps (Supervisor)

The aim is to determine the metallurgical structure in flash welds in stainless steel and its relation to the welding variables and, in particular, to study the problem of grain boundary cracking ('break-up') in the weld zone.

The initial period has been spent establishing metallographic techniques, using specimens supplied by C.E.G.B.

A series of welds have been produced at John Thompson Ltd., Gloucester, and the Superheater Company Ltd., Manchester, for examination at Cranfield.

(iv) Contract Research

A number of topics are also being investigated under research contracts with various Government Departments and industry. These are aimed at producing basic data rather than fundamental studies of the topics. Current contract research topics are:

1. Fatigue properties of light alloy sheet being used for construction of the Concord supersonic aircraft.

2. Torsional creep and low cycle fatigue of stainless steel fuel element cans for the advanced gas cooled reactor;

3. Stress redistribution due to creep in Nimonic 90;

4. Study of effect of grit blasting and metal spraying variables on the bond strength of flame sprayed coatings on steel;

5. Torsional creep of alumina and beryllia at very high temperatures.