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Development of technically and economically viable processes for the conversion and utilization of fossil fuels is a major objective of the DOE Fossil Energy program. Many new and different processes are being investigated in areas of coal gasification, improved power generation and advanced combustion. As these processes evolve to the pilot plant stage and beyond, materials selection and component design become increasingly important for reliable and economical operation. The newsletter is intended to serve as a medium for exchange of information and experiences pertinent to the use of materials and components among the communities interested in the development of fossil energy systems.

Weldability of Fe-Al-Cr Overlay Coatings

Iron aluminum-based alloys are being considered for use as coatings for the protection of furnace wall tubes in coal-fired boilers fitted with low-NO_x burners (especially where over-fire air is supplied separately). The good potential of these alloys is based on their excellent high-temperature corrosion resistance, especially in sulfidizing environments, and because they are significantly less expensive and do not experience the micro-segregation found in Ni-based alloys, nor do they form a brittle interface at the fusion zone as is seen with some stainless steel weld overlays. Laboratory studies have indicated that increasing the Al content of Fe-Al based alloys results in an increase in the corrosion resistance in high-temperature environments containing oxygen and sulfur. Apparently, a minimum Al level of approximately 10% (all compositions are given in weight percent) is required in binary Fe-Al alloys to achieve protective behavior in sulfidizing gases at 500°C, and recent results have indicated that Cr conditions up to 5% provide enhanced protection in simulated low NO_x atmospheres. One problem with Fe-Al welds is that they are sensitive to hydrogen-induced cracking (cold cracking) in a certain compositional range. Earlier weldability studies have shown that the cold-cracking phenomenon is directly related to the Al content of the weld overlay, regardless of the welding parameters. However, welding compositions below approximately 10% Al can be deposited crack free, so that it is of interest to determine if the high-temperature corrosion resistance of such alloys with lower Al contents can be maintained by chromium additions.

The primary objectives of the study reported here were

1. to investigate the effect of Cr on the weldability of Fe-Al-based weld overlays, and to determine Fe-Al-Cr compositions that are not susceptible to cracking;
2. to determine the effects of Cr on the a-Fe_3Al compositional boundary, to determine if the presence of Fe_3Al has a role in the susceptibility to hydrogen cracking; and
3. to evaluate the corrosion performance of weldable Fe-Al-Cr weld overlays at long exposure times.

Weldability Studies
Preliminary weld overlay coatings were deposited using a mechanical gas-tungsten arc welding system (GTAW), with a computer-controlled table and cold wire feeders. Binary Fe-Al welds were produced by depositing Al (1100) filler metal wire onto plain carbon (A285C) steel substrates. Fe-Al-Cr weld overlay claddings were made by simultaneously depositing two filler metal wires: Al (1100) and ferritic stainless steel (430) onto plain carbon-steel substrates. Two filler metal wires were used to produce Fe-Al-Cr welds in order to have independent control over the Al and Cr contents, and to allow for

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systematic variation of these two primary alloying elements. Initially, welds were made with Al contents ranging from 5-15%, and Cr contents of approximately 0-10%; the Al and Cr contents were increased until cracking occurred in order to determine the maximum alloying content achievable in a crack-free weld. Six binary Fe-Al weld overlay coatings, and one ternary Fe-Al-Cr weld overlay were deposited using the parameters shown in Table 1; also shown in the table are the chemical compositions of the alloys deposited, as well as the observed number of cracks.

Table 1. Welding Parameters

Weld	Current (amps)	Voltage (volts)	Al wire feed rate (mm/s)	FeCr wire feed rate (mm/s)	Weld composition (wt%)	No. cracks
A	250	11.1	41.5	0	18.1 Al	4
B	250	11.0	58.0	0	27.1 Al	12
C	250	10.5	17.0	0	6.4 Al	none
D	275	11.0	33.0	0	11.9 Al	1
E	275	11.3	41.5	0	12.4 Al	4
F	300	12.1	25.0	0	5.4 Al	none
G	250	11.3	25.0	60.0	8.9 Al-7.2 Cr	none

Once welds were deposited, they were cooled for 24 hours and were then inspected for cracking by optical microscopy and die-penetrant techniques, and a list was made of compositions that cracked, or did not. Compositions along the crack-no crack boundary were then selected for analysis by transmission electron microscopy (TEM) to determine if the ordered intermetallic, Fe_3Al, was present in welds that experienced cracking. Samples for TEM were removed from welds adjacent to cracks, and from the weld matrix using a focused ion beam (FIB) device.

The cracking behavior of the preliminary Fe-Al welds are compared in Fig. 1 to earlier results in terms of energy input and rate of filler metal feed parameters. This figure shows that even at higher energy input values and filler metal feed rates, the cracking behavior of the binary Fe-Al weld overlays is a function only of weld composition. These results on binary Fe-Al weld overlay claddings confirmed earlier findings, and showed that the previous results are reproducible and that the binary compositional welding boundary is at approximately 10 wt % Al.

The ternary Fe-Al-Cr weld overlay deposit (weld G) was deposited crack-free and had Al and Cr contents of 8.9 and 7.2 %, respectively. The fusion zone of the weld consisted of a columnar grain structure, and appeared to be continuous throughout the fusion zone, as shown in Fig. 2. There was no distinct boundary in the fusion zone, suggesting good mixing between the two filler metal wires in the weld pool during deposition. Nevertheless, this must be confirmed by electron microprobe analysis to ensure that

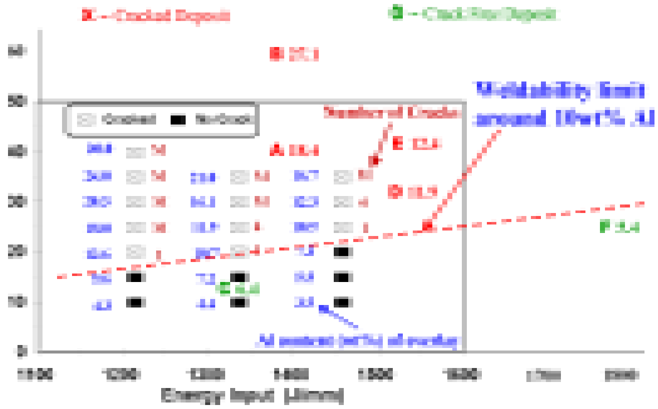

Figure 1. Cracking susceptibility /weldability diagram

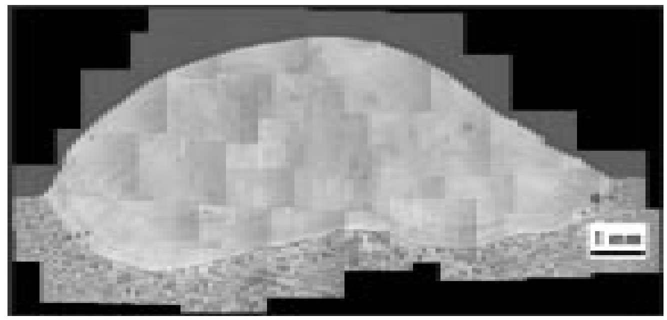

Figure 2. Optical micrograph of a cross section of a Fe-Cr-Al weld overlay deposit (Weld G)

the composition is homogeneous and that there are no mixing issues during welding.

Long-Term Corrosion Testing

Fe-Al-Cr alloys with compositions similar to those of the crack-free weld overlay deposits were cast for use in corrosion tests. Samples were exposed to an oxidizing environment, and to a mixed oxidizing-sulfidizing environment at 500°C for incremental times up to 2000 hours. The compositions of the two corrosive gas environments are indicated in Table 2. Specimen performance in the tests was accessed from total mass change over the exposure times, and from scale morphology observations using scanning electron microscopy and energy dispersive spectroscopy (SEM-EDS).

The compositions of the tested alloys were Fe-10Al, Fe-10Al-2Cr, and Fe-10Al-5Cr, selected on the basis of earlier results of 100 exposures. Figure 3 shows the

Table 2. Compositions of the Corrosive Gases (vol%)

Gas Component	Oxidizing	Oxidizing-sulfidizing
O_2	2	
CO		10
CO_2	15	5
H_2		
H_2O	6	2
H_2S		0.12
SO_2	0.12	
N_2	Bal	Bal
log pO_2	-2	-19
log pS_2	-46	-8

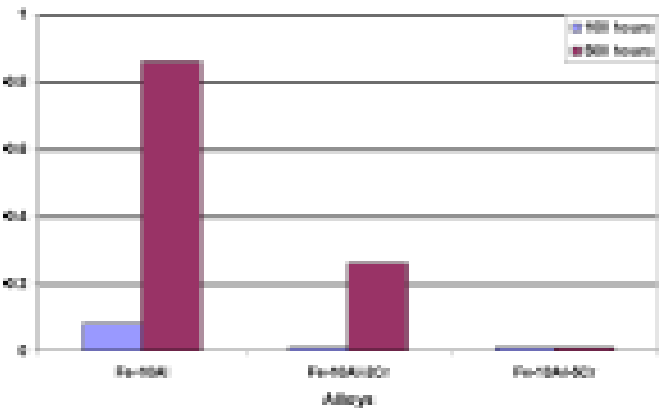

Figure 3. Corosion results after 500h at 500°C in an oxidizing environment

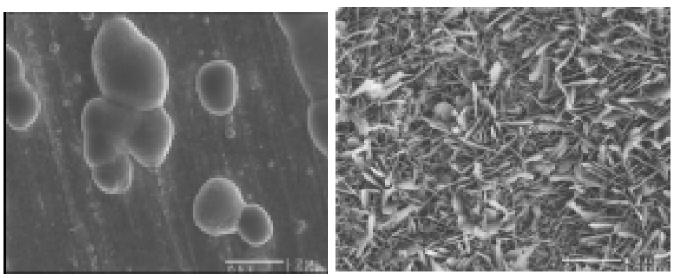

Figure 4. Surface morphologies of corrosion scales formed on Fe-10Al after 500h at 500°C in an oxidizing environment

marked reduction in mass gain during the 100 and 500 hour exposures to the oxidizing gas, due to Cr additions to the Fe-10Al base. The scale morphology on the Fe-10Al alloy indicated two types of scales: sphere-like nodules that formed on areas of bare metal, and plate-like scale that grew out of the sphere-like nodules, Fig. 4. Both the

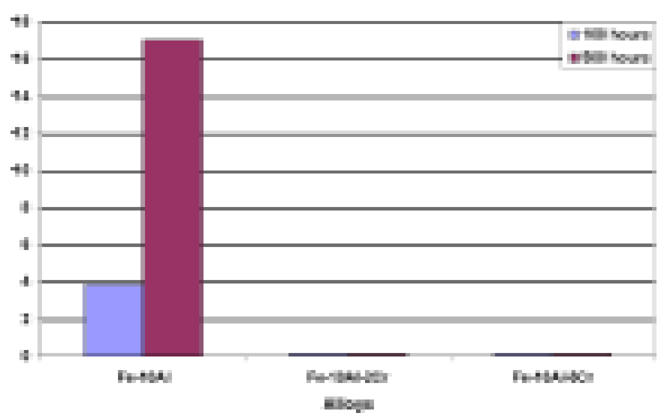

Figure 5. Corosion results after 500h at 500°C in an oxidizing-sulfidizing environment

scales were iron oxide compounds.

Similar large reductions in mass gain with added Cr were observed in the mixed oxidizing-sulfidizing environment after 100 and 500 hours, Fig. 5 (note that the mass gain axis is much larger than that in Fig. 3). The Fe-10Al sample exhibited a thick, block-like corrosion scale that cracked and easily spalled; this scale completely covered the sample, and was identified as iron sulfides (Fig. 6). The corrosion results for the Fe-10Al-5Cr also were promising, but longer exposure times are required to fully characterize the long-term corrosion behavior of these alloys.

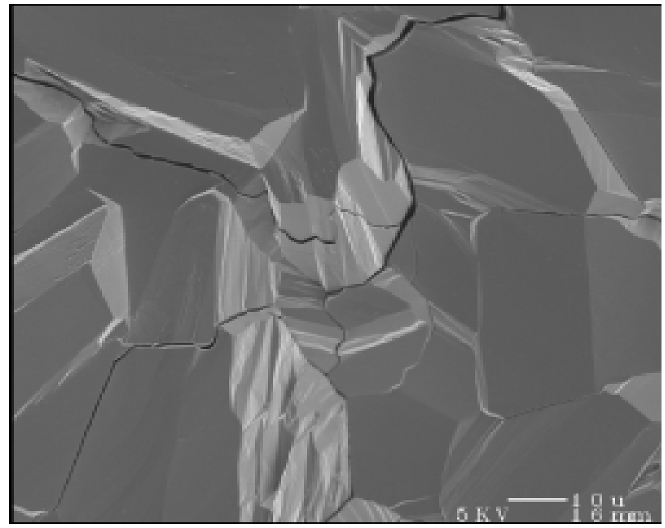

Figure 6. Surface morphologies of iron sulfide scales formed on Fe-10Al after 500h at 500°C in an oxidizing-sulfidizing environment

Next Steps

Future work will include depositing Fe-Al-Cr weld overlays over a wider range of Al (5-15%), and Cr (0-10%) compositions, and the compositional welding boundary will be established. TEM analysis will be performed on compositions on either side of this boundary to determine the composition range which results in the presence of the intermetallic phase Fe_3Al which is known to influence the weld susceptibility to hydrogen cracking. Long-term corrosion testing of selected crack-free welds with the highest alloying contents will be exposed in the oxidizing and mixed oxidizing-sulfidizing environments for up to 2000 hours. It is expected that the results will identify ternary Fe-Al-Cr weld overlay coating compositions that are immune to hydrogen cracking, and are corrosion resistant for long times.

Abstracted from: J. L. Regina, J. N. DuPont, and A. R. Marder, *Lehigh University*, "Weldability of Fe-Al-Cr Overlay Coatings for Corrosion Protection in Oxidizing/Sulfidizing Environments," Report ORNL/Sub/95/SU604/03, March 2003.

Supercritical Steam Turbine Issues

Power generation based on supercritical (SC) steam technology was pioneered in the USA in the late 1950's, followed by Russian plants in the early 1960's. The first commercial plant in the USA, Philo 6, was commissioned in 1957 by the Ohio Power Company and operated until 1979; it had steam design parameters of 31 MPa, 610/565/538°C and as rated at 120 MWe. The first SC steam unit in Russia was built at Kashira in 1966, and had steam conditions of 30.6 MPa, 650/565°C. Currently, there are 557 operating SC steam power units worldwide, with a total installed capacity of 303.2 GW. These are listed by country in Table 1. In the last decade, the traditional leaders of the field, USA and Russia, have left the field almost entirely; the new leaders are Japan, South Korea, China, and Germany.

Table 3. Supercritical Steam Turbine Market, by Country

Country	Total Cumulative		Installed in last 10 years	
	Total capacity GWe	No. Units	Total capacity GWe	No. Units
USA	106.6	156	0	0
Japan	68.2	108	20.9	26
Russia	49.2	128	2.7	4
Germany	14.8	31	8.7	12
Korea	13.5	24	13.5	24
China	13.3	223	9.9	15
Others	37.6	87	8.5	17
Total	**303.2**	**557**	**64.2**	**98**

The major equipment suppliers of supercritical steam power plants are:

- GE Power Systems;
- Siemens Power Generation (including the former Siemens KWU/Westinghouse, later Siemens/Westinghouse Power Corporation);
- Leningrad Metal Works (LMW);
- Toshiba Corporation;
- Alston (including former ABB and GEC-Alstom), and
- Mitsubishi Heavy Industries (MHI).

The total cumulative number and total capacities of supercritical steam turbine installations supplied by these major manufacturers are shown in Table 2.

Subcritical to Supercritical Issues

A major differentiation between sub-critical and SC steam units is that, in the former, steam and water are separated in a drum, and the water is then recirculated through the furnace walls, whereas the latter use once-through fluid flow. Supercritical technology promises higher efficiency compared to sub-critical steam conditions (less than 201 bar, etc), which translates to reduced fuel costs and lower CO_2 emissions per unit of coal burned. In addition, SC steam units have improved part-load efficiencies, and allow faster load changes with higher ramp rates: while drum boilers can change load at a maximum rate of about 3 percent per minute, once-through SC steam boilers can step up load by 5 percent per minute. These advantages come at a cost:

Table 4. Supercritical Steam Turbine Market, by Supplier

OEM	Total Cumulative		Installed in last 10 years	
	Total capacity GWe	No. Units	Total capacity GWe	No. Units
GE	71.6	111	14.1	25
Siemens	56.8	93	8.6	11
LMW	41.3	85	8.6	15
Toshiba	39.5	64	7.2	10
Alstom	25.7	42	5.9	9
MHI	21.5	35	11.8	17
Others	46.8	127	8.0	11
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- the need for much greater control of the water chemistry;
- the need for fast-response and adaptive tuning of control systems; and
- an increased capital cost (of around 5 percent).

In order to sustain flexibility of operation, the steam turbine must have the same capabilities as the rest of the boiler system. The biggest differences in the steam turbines for SC steam operation compared to sub-critical steam plants, follow simply from the higher steam parameters in SC steam plants. Hence, one of the major issues concerns the materials to be used for the high-pressure (HP) turbine. Wall thickness needs special attention: thick-section components are undesirable from the standpoints of fabricability/weldability, and susceptibility to thermal fatigue, and must be avoided without compromising material strength. The material used for the HP turbine section should not only allow wall thicknesses to be as thin as possible, but should also show good resistance to oxidation by the steam to avoid the formation of excessive oxidation products, the exfoliation of which can lead to tube blocking and turbine erosion.

For the intermediate-pressure (IP) section, there are relatively few differences between sub- and supercritical steam units, and where the reheat temperature is 540°C or lower, these differences would be minor. Since the temperature of the steam to be handled is the same, the low-pressure (LP) turbine section is usually the same as those in subcritical plants. However, double reheat between the

HP and IP sections sometimes is necessary to avoid excessive water condensation on the blades of the final-stage rotor, which can lead to excessive erosion. Nevertheless, most LP turbines may be used with advanced steam conditions, and do not require the use of materials specifically developed for higher temperatures.

Features of Modern Steam Turbines

The internal design of steam turbines has undergone a long, evolutionary development process. Advances in computational fluid dynamics, especially the ability to make three-dimensional calculations, have resulted in the development and use of optimally-twisted turbine blade designs for higher efficiency. Another feature, found in GE steam turbines, is the use of an increased number of stages (stage count) set in the same rotor span, which GE calls 'Dense Pack Steam Turbine Technology.' This approach also features the incorporation of reduced exit angles, longer blades and increased annulus area, decreased nozzle solidity, twisted blade airfoils for all stages, and improved tip sealing. For a typical 60 Hz steam turbine HP stage, these improvements can result in an increase in steam path efficiency of 3 percentage points. One of the most important features of the Dense Pack concept is the use of increased stage reaction levels.

Turbines typically are designed to develop specific pressure drops across each stage. In 'impulse' designs most of the pressure drop occurs across the vanes, which accelerate and turn the gas flow to produce jets that impinge on the rotating blades; in an impulse design ('≈0% reaction') there is little pressure drop across the rotating blades, which simple deflect the steam flow without accelerating it further. However, in a 'reaction' design the moving blade also extracts work from the gas steam; in a symmetrical reaction stage design, equal pressure drops occur across the vanes and the rotating blades ('50% reaction'), and the blades and vanes can use the same profile. In practice, the blade is shaped so that the percentage of reaction at the blade tip and root are different, in order to prevent centrifuging of the steam flow to the blade tips. The first of the state-of-the-art Dense Pack designs to be installed in a new plant will be in the Tangjin power plant in South Korea, which is due to be commissioned in 2005. This plant will have steam conditions of 24.4 MPa, 566/593°C, with an output of 2 x 520 MWe, and an efficiency of 43.5%.

The Seimens concept of 3-D blade design with variable reaction is based on the idea of being able to select the level of stage reaction. The shape of conventional blades and vanes originally was based on either an impulse or reaction design, with the same degree of reaction applying to all stages. The merit of the 3-D variable design is that it allows the reaction of each stage to be set on an individual basis, so combining the effects of both multistage reaction blading and low reaction impulse blading. One of the latest examples of Seimens' supercritical steam turbine technology is in the 900 MW, 5 cylinder HMN model, installed at Boxburg in Germany. The internal turbine efficiency demonstrated for this machine was 94.2% for the HP section, and 96.1% for the IP section; the overall plant efficiency is 43%. This latest generation of supercritical steam turbines is based on martensitic steels developed some 10-20 years ago, and the rotor forgings are based on 9-12% CrMoVNbN steels which may contain up to 1.5% Mo.

For steam temperatures >700°C, Ni-base alloys will be required in critical steam turbine components. Currently, HP turbine inlet conditions are limited by materials capabilities to approximately 30 MPa, 600/620°C, corresponding to a plant efficiency of 47% based on bituminous coal, and a moderate climate.

Based on: P. Luby, *Ingchem, Bratislava*, "Supercritical Systems," Modern Power Systems, Vol. 23(8), 27-32, August 2003. Published by permission of Wilmington Publishing Ltd.

Editor's Note: In August 2003 at a ceremony in Columbus. Ohio, ASME International designated the Philo Unit 6 as an ASME Historic Mechanical Engineering Landmark, in recognition of the pioneering concepts that it introduced, and for the role it played as a prototype for many large, efficient power plants throughout the world. The steam turbine rotors from Philo 6 are now part of a sculpture located in front of American Electric Power's headquarters building in Columbus, Ohio.

Supercritical Steam Comes to CFBs

The first commercial, circulating, fluidized-bed (CFB) steam-generating boiler built by Foster Wheeler Energia was a 5 MW wood residue and peat-fired boiler supplied to Suomen Kuitulevy, Pihlava, Finland in 1979, and was soon followed by a 20 MW plant at Kauttua, Finland. Both units were designed for combined heat and power (CHP) production. In subsequent years, the user base of CFBs has expanded to include a significant number of boilers in the United States, built in the 1980s and 1990s and fired on coal and waste coal. The size of CFB-based plants has increased with time, as illustrated in Fig.7, attaining the lower end of the size range of interest to electric utilities in recent years.

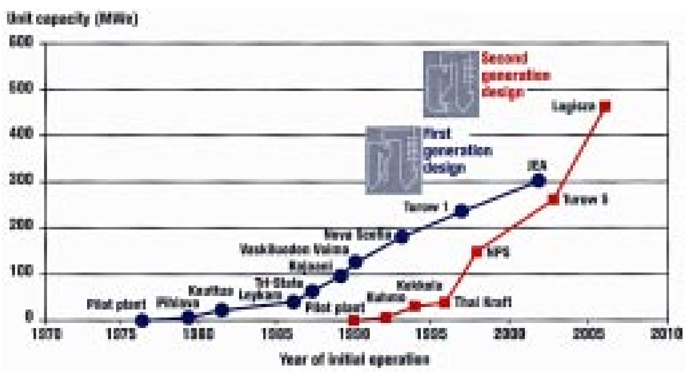

Figure 7. Scale-up history of Foster Wheeler CFB boilers

The scale-up of CFB boilers has been based on advances in understanding of the underlying technology that have resulted from measurements from existing units, as well as laboratory tests and related theoretical studies. The first CFBs (first-generation design) used a membrane-wall construction for the furnace enclosure, which acted as the main evaporative surface, with a refractory lined cyclone to return the solids to the lower furnace region. Foster Wheeler's second-generation design uses an integrated separator within an evaporative or steam-cooled membrane enclosure, so eliminating the need for a separate heavy, thick refractory structure. In addition, the final superheater and/or reheater is contained in an integrated recycle heat exchanger (INTREX). This consists of one or more tube bundles in a bubbling bed situated so that it further cools the solids collected by the separator before they are returned to the furnace. In addition, solids from the furnace can internally circulate through the INTREX tube bundles to ensure a sufficient supply of hot solids at all loads. By controlling the flow rate of solids though these tube bundles, the heat absorption can be varied to provide a degree of operating flexibility. Also, since the INTREX is fluidized by clean air, high-temperature corrosion considerations are less severe than for superheaters in pulverized coal fired-systems. A schematic diagram showing the cross section of an INTREX unit is shown in Fig. 8.

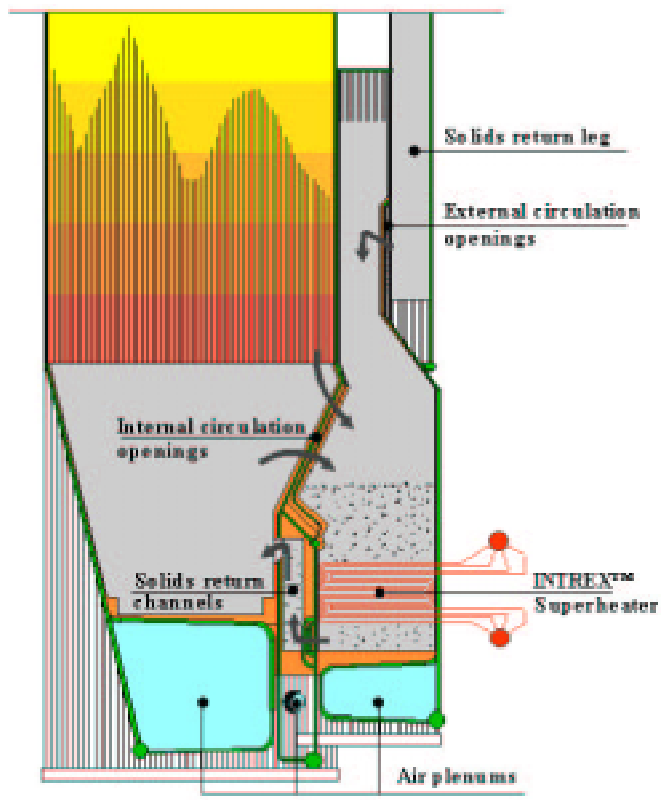

Figure 8. Schematic diagram of an integrated, recirculating heat exchanger (figure published by permission of Foster Wheeler Power Group Inc.)

First-generation technology reached its peak size with 2 x 300 MW(e) coal- or petroleum coke- (or any combination)-fired boilers at the Jackson Energy Authority's North Side Plant in Florida. The largest second-generation CFB in operation is the Turow Unit 5 in Bogatynia, Poland. This is fired on brown coal with a moisture content of the order of 50%, so that the furnace is as large as those of the Jacksonville units to cope with the larger flue gas volume.

The largest CFB units built so far have used natural circulation boilers and subcritical steam parameters: the Turow unit 5 and two other identical units under construction employ natural circulation and state-of-the-art steam parameters of 568/568°C and 171/40 bar. There is no reason why a CFB boiler should not be designed for supercritical parameters and, in fact, the lower heat fluxes in the furnace compared to pulverized coal-fired technology is an attractive feature. The high heat transfer coefficient of an INTREX integrated heat exchanger used as the final superheater/reheater results in a considerable reduction in size compared to conventional superheaters and reheaters.

The major factor that has limited increasing steam temperatures in such units has been the steam turbine characteristics, since steam turbines for supercritical steam parameters in the less than 300 MW(e) size range have generally not been available. This barrier has now been removed, and Foster Wheeler Energia is contracted to design and build a 460 MW(e) supercritical CFB unit for Poludniowy Koncern Energetyczny SA (PKE) at Lagisza in southern Poland. This unit will likely receive coal from ten different coal mines, and will also have an option to burn coal slurry; Table 5 indicates the range of coal compositions. There is good experience of co-combusting coal slurry with coal in two CFBs that have been in operation in Poland since 1999.

Table 5. Coal Characteristics

Country	Total Cumulative		Installed in last 10 years	
	Total capacity GWe	No. Units	Total capacity GWe	No. Units
USA	106.6	156	0	0
Japan	68.2	108	20.9	26
Russia	49.2	128	2.7	4
Germany	14.8	31	8.7	12
Korea	13.5	24	13.5	24
China	13.3	223	9.9	15
Others	37.6	87	8.5	17
Total	**303.2**	**557**	**64.2**	**98**

The Lagisza CFB will employ state-of-the-art technology for once-through boiler design, based on the Benson vertical technology developed by Siemens and licensed by Foster Wheeler. One structural advantage is the fact that the vertical tubes of the furnace enclosure are self supporting, and so do not require support straps to counteract thermal growth, as are required in spiral-wound once-through boilers. In this system, a single up-flow evaporative pass is used, in which the low mass flow rate results in low steam and water pressure losses, as well as in low auxiliary power consumption. As a result, a mass flux of 600 kg/m^{2}s or lower can be obtained, compared with more than 1100 kg/m^{2}s in conventional designs. Further, at low mass flow rates, the tubes subjected to the greatest heat flux receive the highest flow rate because of natural circulation flow characteristics. Since a single-flow evaporative pass is used, full variable pressure over the operating load range can be used to more effectively match steam and turbine blade temperature for cyclic operation. As mentioned earlier, the uniformity of firing due to the circulating bed results in a relatively uniform temperature distribution in the furnace in both horizontal and vertical directions, which is also advantageous for once-through boiler designs.

Overall, the design follows the same principles as in earlier Foster Wheeler designs for large scale CFBs, with the furnace acting as the evaporator. The superheaters and reheaters are located in the back pass, while the final superheater and reheater are INTREX units. The scale-up required from the Turow 5 unit was not significant, particularly in terms of the depth of the furnace where the increase will be negligible, while the height of the boiler will be some 10% greater than Turow and the width somewhat more. More fuel feeders and air registers have been incorporated to account for this increase. Siemens' extensive experience with Benson Technology will significantly contribute to issues related to controls and startup and has led, for instance, to the use of advanced controls to ensure that feeder trips will not cause any significant imbalances on the water side.

In designing the plant, a fuel chlorine content somewhat higher than that usual in bituminous coal was assumed, and lower steam values were selected to avoid any possibility of superheater corrosion, which certainly would have been an issue in a conventional pulverized coal-fired plant. The steam parameters of the Lagisza CFB are shown in Table 6. The total efficiency is expected to be in excess of 43%, and the gaseous emissions will meet the requirements of the new European Union Large Combustion Plant directive. Mechanical erection of the new plant is scheduled for completion in February 2006, with commercial operation at the end of September 2006.

Table 6. Steam Characteristics

OEM	Total Cumulative		Installed in last 10 years	
	Total capacity GWe	No. Units	Total capacity GWe	No. Units
GE	71.6	111	14.1	25
Siemens	56.8	93	8.6	11
LMW	41.3	85	8.6	15
Toshiba	39.5	64	7.2	10
Alstom	25.7	42	5.9	9
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Abstracted from: "Taking CFB Supercritical," Modern Power Systems, pp. 37-39, April 2003. Published by permission of Wilmington Publishing.

Corrosion of Materials in Biomass Fired Power Plants

In Scandinavia, there have been serious efforts to reduce CO_2 emissions by using CO_2-neutral fuels that do not contribute to the greenhouse effect. The Danish government has pledged to reduce CO_2 emissions to 80% of the 1988 levels by the year 2005. So far, Denmark has concentrated its efforts on straw, and there are currently seven straw-fired combined heat and power (CHP) plants in operation, and one wood chip-fired boiler. A plant co-fired by straw and coal recently has commenced operation.

Straw and wood chips typically contain lower levels of S and ash than does coal, but the content of chlorine and alkali metals, especially K, can be significantly higher than found in coal. The potential for producing alkali chlorides in the flue gas gives rise to concerns about significant fireside corrosion problems that are different from those for which experience is available from coal-fired boilers. Thus, combustion of straw releases SO_2 and KCl into the flue gas and, where the gas contacts surfaces that are below the dew point of the condensable compounds formed, deposition can result. The compounds of most interest from the viewpoint of the potential for corrosion problems of superheater components are KCl and K_2SO_4. Over the past decade, many field investigations have been undertaken in Denmark of corrosion resulting from straw combustion, and this paper highlights the significant results and compares likely corrosion mechanisms and rates from straw-, wood chip-, and co-firing with straw and coal. The results draw on field tests in various plants as well as laboratory investigations. A summary of the data from the plants, and the types of investigations conducted, is given in Table 1. The four plants from which results are included are Ensted; Maribo Sakskøbing; Masnedø; and Rudkøbing. Three types of corrosion investigation were undertaken:

Table 7. Summary of In-Situ Investigations

Plant	Fuel	Output (MWth)	Steam T (°C)	Steam P (MPa)	Investigations
Masnedø[1]	straw	33	520	9.2	• Deposit studies: probe and matured deposits. • Aerosol measurements • Corrosion studies: probes; test tubes in existing SH and in test SH (≤600°C)
Rudkøbing[1]	straw	10.7	450	6.1	• Deposit studies: probe and matured deposits. • Corrosion studies: probes
Maribo Sakskøbing[1]	straw	33	540	9.3	• Mature deposit studies • Corrosion studies: test tubes in existing SH
Ensted[1]	straw	99.4	470	20.1	• Deposit studies: probe and matured deposits. • Aerosol measurements • Corrosion studies: probes; test tubes in existing SH
Ensted[1]	wood chips	16.3	470-540	20.1	
Studsrup[2]	coal-20% straw	380	540	14.3	• Deposit studies • Aerosol measurements • Gaseous emissions • Corrosion studies: probes, test tubes in existing SH

[1] grate-fired, CHP
[2] suspension-fired

• exposure of metal rings on air/water-cooled probes;
• exposure of test tubes in a test superheater; and
• exposure of test tubes in existing superheaters.

Straw Firing

Figure 1 is a schematic drawing of the corrosion morphology typically found on type 347H stainless steel (Fe-11Ni-19Cr-Mn,Nb, in weight percent) exposed in straw-fired plants. Selective removal of Cr (where the metal

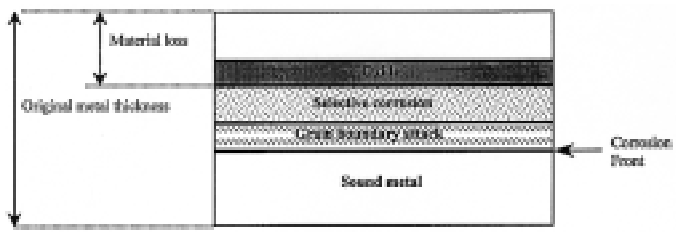

Figure 9. Schematic representation of corrosion morphology in straw-fired plants

becomes porous) is observed, as well as grain boundary attack, such that the sum of internal corrosion attack can be greater than 0.5 mm. For austenitic steels, grain boundary corrosion is a precursor to corrosion within the grains. The corrosion products formed are Cr oxides and Fe oxides; typically, these are present at the surface of the specimen. In many cases Ni also is present in the outer corrosion product as non-reacted metal. If Cl is detected in the corrosion morphologies, it is located close to or at the corrosion front. Chlorine present at the corrosion front reacts to form Cr chloride, and the surface grains become depleted in Cr. However, adjacent, unaffected grains have been found to contain both Cr and O, showing that the partial pressure of oxygen is high enough to convert Cr chloride to Cr oxide. Typically no K is detected in this area. Even at metal temperatures lower than 500°C, Cl-containing corrosion products still are found at the corrosion front. The corrosion product morphology on austenitic alloys gradually changes with temperature: at metal surface temperatures below 500°C a protective oxide is formed whereas, at around 500-520°C, grain boundary attack as well as protective oxide formation can occur, as illustrated in Fig. 4 for alloy Esshete 1250 (Fe-9.5Ni-15Cr-6Mn-Mo,V,Nb).

Preferred corrosion attack of Cr-rich austenite grains in a martensitic steel also is observed for

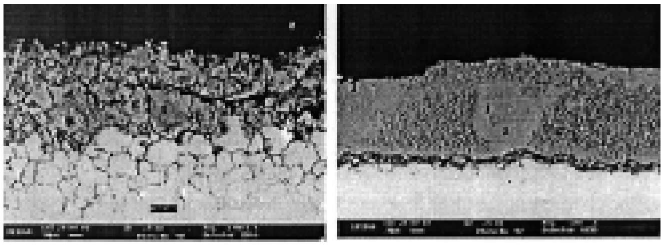

Figure 10. Cross sections of surfaces from the same specimen of Esshete 1250 exposed for 8,690h at 513°C (at Masnedø), showing (a) grain boundary attack, and (b) protective scale formation.

alloy HCM12 (Fe-12Cr-W,Mo,V,Nb,Cu,N)) at high temperatures. Even at temperatures below 500°C, where the rate of corrosion is minimal due to the formation of a protective scale, preferential attack has been observed after three years of exposure.

Corrosion Mechanism: Short-term deposition experiments have shown that KCl constitutes the initial condensate, so that chlorine must be released from such deposits to initiate corrosion. The initiation process may be any of a combination of reactions between KCl, SO_2, O_2 and water vapor which release either HCl or chlorine gas. The released chlorine then migrates through any protective scale, and reacts preferentially with Cr (as well as Mn) at the metal-oxide interface to form $CrCl_2$ or $CrCl_3$. The Cr chloride formed migrates outward to a area of higher oxygen partial pressure, where it is converted to Cr oxide and chlorine. Although Cr chloride has a lower volatility compared to Fe chloride, the temperature gradient due to the difference between metal and gas temperatures encourages the evaporation of metal chlorides. Further, Cr chloride oxidizes at lower oxygen partial pressures than do both the chlorides of Fe and Ni. The chlorine thus released then migrates back to the corrosion front to restart the cycle of formation of metal chlorides.

This behavior explains the voids seen at grain boundaries at the corrosion front (due to the evaporation of metal chlorides), and also explains the presence of oxides at grain boundaries or within the grains, where the partial pressure of oxygen is higher that at the corrosion front. For austenitic materials, grain boundaries are the initial site of attack, followed by attack of Cr within the grains. Preferential attack may also occur of Cr-rich carbides present in the grain boundaries.

A similar chlorination reaction occurs for Fe reacting to from an iron chloride. Iron chloride will migrate more readily out of the corrosion product, since it is more volatile than Cr chloride. Also, since Fe chloride reacts to form oxides at higher oxygen partial pressures than does Cr chloride, it would be expected to form oxide outside (on the gas side) the Cr oxide. At lower temperatures, which do not favor evaporation of Cr chloride, Fe chloride will continue to evaporate from the corrosion front, and promote active oxidation.

Corrosion Rates were determined under the assumption that the corrosion kinetics are linear with time. This is clearly acceptable at higher temperatures where non-protective oxides are present; however, at temperatures below 500°C where more-protective scales are formed, the kinetics are probably closer to parabolic. Nevertheless, for comparison purposes, linear kinetics were applied. Figure 7 summarizes data for a range of alloys from 2.25-30% Cr exposed on a probe at a straw-fired plant. Corrosion rates are presented as (mm/1000h), based on metallographic measurement of actual metal loss as well

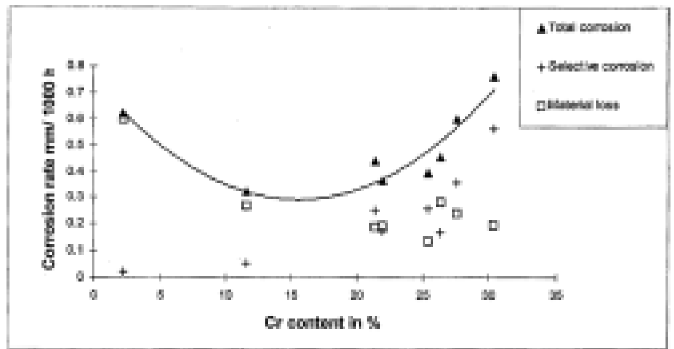

Figure 11. Corrosion rate in straw-fired CHP plant (Masnedø) as a function of alloy Cr content (metal temperature approximately 550°C)

as internal penetration, which are summed to provide the figure for 'total corrosion.' Note that the low-Cr steels exhibited very high levels of metal loss, whereas the higher-Cr steels were characterized by severe internal corrosion. These results suggest that there is a minimum in total corrosion rate at an intermediate Cr content of 15-18%.

Figure 8 summarizes the temperature dependence of corrosion of type 347 stainless steel based on exposures in a test superheater in a straw-fired plant. Both fine-grained

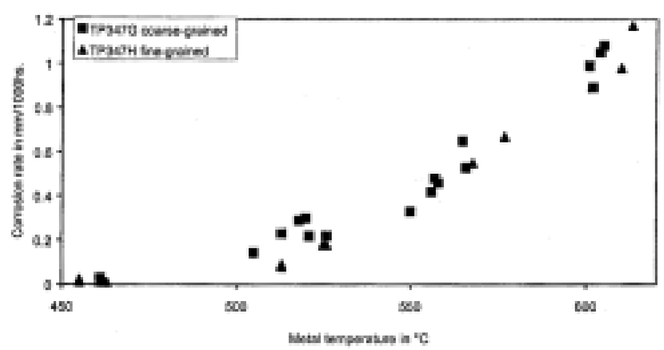

Figure 12. Temperature dependence of corrosion rate of type 347 stainless steel in straw-fired CHP plant (Masnedø)

and coarse-grained versions of this alloy were exposed and, while there was some spread in the corrosion rate data at the higher temperatures, there was apparently no significant effect of alloy grain size. Figure 9 collates the corrosion rates of fine- and coarse-grained versions of 347 from four straw-fired plants. Where more accurate data could not be obtained, the metal surface temperature reported was taken to be the steam temperature in the test tubes in the existing superheaters plus 20°C.

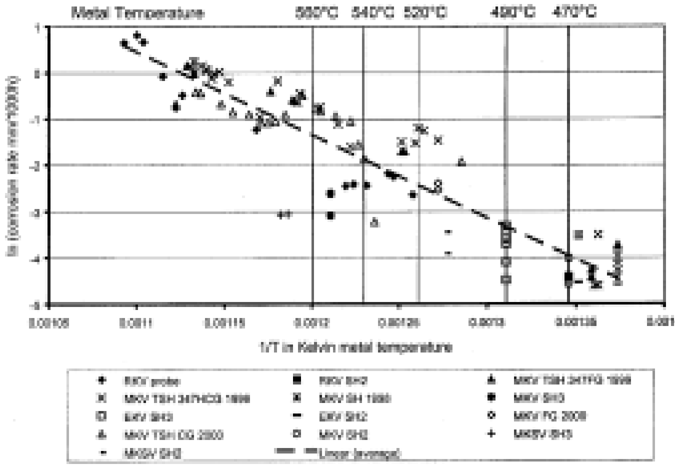

Figure 13. Temperature dependence of corrosion rate of type 347 stainless steel-data from all straw-fired tests

There is general agreement in the results from the four plants, although there is also a significant spread in the data; the reason for the spread is not understood, but may have been connected to differences in the flue gas temperatures. The expression for the corrosion rate derived from these data is:

$$c = \exp\left[(A \bullet b/T_m) + C(T_g - T_m) + d\right]$$

where: c is the corrosion rate in mm/1000 h
T_m is metal temperature in °K
T_g is gas temperature in °K
A is a constant related to the alloy composition (such as the amount of Cr, etc.)
C is a constant related to the flue gas temperature
b and d are empirical constants.

Wood Chip Firing

A comparison between the impurity contents and levels in straw and wood chips indicates that the latter has less ash and fewer corrosive compounds; straw contains approximately an order of magnitude more K and Cl than in wood chips. On this basis, it appears that wood chips would be a less corrosive biomass alternative to straw and, as a consequence, there has been no similar investigative program for corrosion concerns in wood chip firing. As a result, the wood chip-fired boiler at Elsam's Ensted CHP plant in Denmark is fabricated from a 12Cr1Mo-1W steel, and has an outlet steel temperature of 540°C, compared to an outlet steam temperature of 470°C for the companion straw-fired boiler.

Corrosion Morphology and Mechanism: Analysis of the ash from the high-temperature components in the wood chip-fired boiler indicated the presence of K_2SO_4 and $CaSO_4$ in the deposits close to the oxide scale and, in some cases, KCl closer to the flue gas-deposit interface. However, since K and Cl also were detected at and near the corrosion front, there is an indication that a corrosion mechanism similar to that in straw-fired boilers can occur. Specimens from two adjacent type 347 tubes that had been exposed in the plant at the same time for 2000 hrs showed mostly protective scale formation. However, one specimen had areas of grain boundary attack, with non-protective oxide formation.

Corrosion problems were encountered in the panel walls of the Ensted boiler. The calculated surface metal temperatures in the corrosion affected area were 580-600°C. The walls required extensive repairs using weld overlay of alloy 625 (Ni-21Cr-9Mo-Nb,Ta,Al,Ti). Examination six months after the repair revealed a Cr-rich scale, with a subjacent Cr-depleted layer in the alloy; the maximum depth of internal corrosion was approximately 10 μm. No grain boundary attack was observed in the weld overlay, which contained no Cr carbides at grain boundaries. If the overall corrosion attack had been similar to that in straw-fired plants, the depletion of Cr from the surface of the alloy would have been expected to result from the formation of Cr chlorides, which then would have oxidized to Cr oxide. Of note is the fact Ni, Cl, and O were found on the surface of the overlay; while Ni reacts somewhat less readily with Cl than does Cr, Ni-Cl-rich corrosion products are less readily oxidized at higher oxygen partial pressures, which may result in a slowing of the active oxidation mechanism.

Corrosion Rates: The limited data collected for type 347H stainless steel in wood chip-fired boilers in Denmark are compared in Fig. 12 to the data for straw firing. Where rapid corrosion was observed, there was a large contribution from grain boundary corrosion, and the overall corrosion rate was within the range of results from straw firing. In contrast, when protective oxides formed, the corrosion rates were below those for straw firing.

Co-Firing of Coal and Straw

Elsam has conducted an investigation at the Studstrup plant of the feasibility of co-firing coal and straw, and its

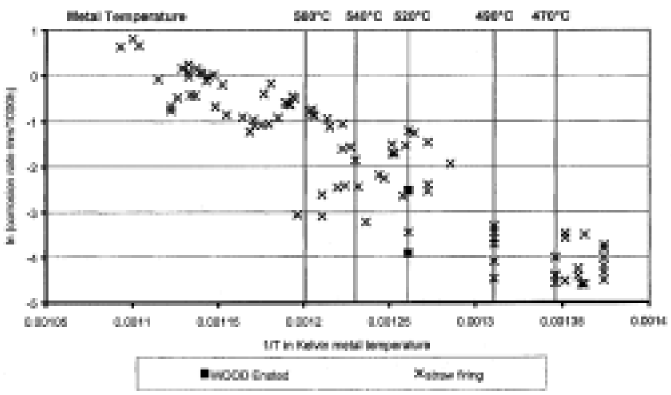

Figure 14. Comparison of temperature dependence of corrosion rate of type 347 stainless steel in straw-fired and woodchip-fired boilers

effect on corrosion, ash deposition, and aerosol formation. On the basis of the positive results obtained, a co-fired plant is now in operation. This section discusses results from long-term exposures in a suspension-fired boiler burning 10 or 20% straw (percentage on an energy basis).

Corrosion Morphology: Figure 13 summarizes the trend in chemical composition of the ash adjacent to the corrosion products on type 347 fine-grained stainless steel when burning coal; coal plus 10% straw; or coal plus 20% straw. The main elements detected in the ash were Al, Si, S, K, Ca, and Fe. As the proportion of straw in the fuel increased, the Al and Si content of the ash decreased, whereas the percentage of S and K increased. These findings were supported by deposition studies. Note that

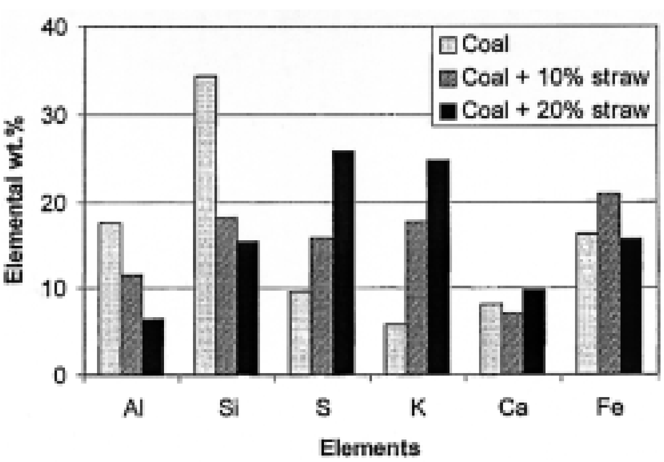

Figure 15. Average composition of main elements in ash adjacent to coerrosion products on type 347 FG stainless steel in coal-fired, coal+ 10% straw-fired, and coal+ 20% straw-fired boilers

no Cl was detected in the deposits or corrosion product, nor at the corrosion front. The ash contained particles rich in Al, Si, K and O in a matrix of K_2SO_4. Iron oxide precipitates also were present within this matrix. The corrosion morphologies for straw co-firing at low metal temperatures were similar to those found in coal-fired plants, comprising an outer layer of iron oxide and an inter layer of iron-chromium oxide. For the higher alloys, a thin Cr-rich oxide was formed, whereas on the lower-alloy steels, thicker scales formed. Sulfur, in the form of sulfate or sulfides, was present within the oxide. At higher temperatures (approximately 580°C) there were additionally large, shallow oxide pits present when co-firing with 20% straw, especially with the austenitic steels. Sulfates or sulfides were detected at the base of the oxide pits.

Corrosion Mechanism: It is proposed that upon combustion, KCl from straw reacts with Al_2O_3, SiO_2, as well as O_2, H_2O and SO_2 to form K_2SO_4, potassium-aluminum silicates, while chlorine is released as HCl. These compounds deposit on the cooled metal surfaces, and the HCl departs with the flue gas. Increasing the straw content from 10-20% results in a greater amount of KCl in the combustion chamber, which produces more K_2SO_4 for deposition, and increased emissions of HCl from the stack. Observations are that corrosion increases with K_2SO_4 concentration in the deposit, indicating that this is the corrosive species in the deposit. Iron oxide at the oxide-molten salt interface can react with SO_3 to form iron sulfate, and it is known that a eutectic which has a melting point of 621°C forms between iron sulfate and potassium sulfate (at approximately 94% K_2SO_4). The two criteria necessary for the formation of a molten eutectic are (1) high concentration of K_2SO_4 on the surface, and (2) a surface temperature close to the eutectic melting point. Laboratory measurements indicated that a mixture of K_2SO_4 and Fe_2O_3 first melts at 586°C; further, trace amounts of other elements may further reduce the eutectic melting temperature. It is, therefore, suggested that low-temperature hot corrosion occurs at the higher temperatures with 20% straw co-firing: $Fe_2(SO_4)_3$ forms a melt with K_2SO_4 and, due to SO_3 gradients, $Fe_2(SO_4)_3$ migrates to the outer part of the melt and precipitates Fe_2O_3. The net result is that at temperatures in the range 580-600°C, the presence of K_2SO_4 leads to acidic fluxing of the 'protective' Fe_2O_3 scale.

Corrosion Rates: Figure 16 is an Arrhenius-type plot (assuming parabolic kinetics) of the corrosion rates of alloy 347FG as a function of temperature. In the plot, the units of the parabolic rate constant (k_p) are (μm^2/1000h). This diagram indicates that the corrosion rates in straw co-firing lie in the same region as those from coal firing, and significantly below those for straw firing. For specimens exposed to 10% straw co-firing, the corrosion rates can be considered as similar to those for coal firing at all temperatures, even those where there is an increased flue gas or metal temperature. For 20% straw co-firing at low

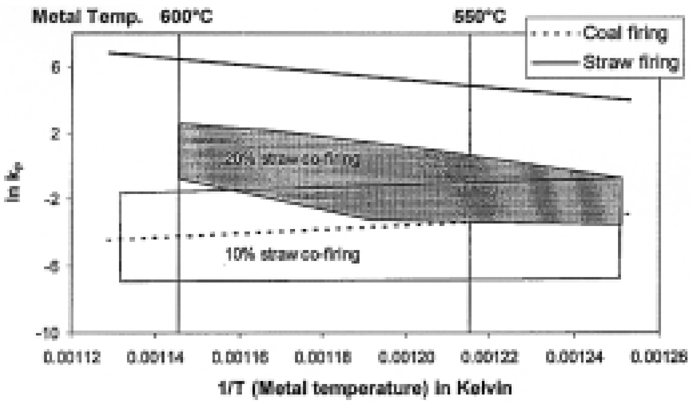

Figure 16. Comparison of temperature dependence of corrosion rate of type 347FG stainless steel in straw+coal co-fired, straw-fired, and woodchip-fired boilers

temperatures, the corrosion rate is also similar to coal firing. There is an increase in the corrosion rate at high temperatures due to the change in corrosion mechanism, as iron sulfate-potassium sulfate melt is formed. Note that the corrosion rates are specific to the investigations conducted at the plants in Denmark, and the results described are likely to be dependent on the coal and biomass type used.

Abstracted from: M. Montgomery, *Technical University of Demark*, O. H. Larsen, *Elsam*, and O. Biede, *Energi E2*, "Corrosion and Materials Performance in Biomass-Fired and Coal-Fired Power Plants," Paper 03356, presented at Corrosion/2003, San Diego, California. Published by permission of NACE International.

Recent Developments

A New Coal-Fired, Supercritical Steam Power Plant Under Construction in Iowa

MidAmerican Energy Company has started construction of a 790 MWe coal-fueled power plant at the Council Bluffs Energy Center in Iowa. The plant will employ "advanced supercritical" technology, and will also incorporate advanced technologies for clean-coal conversion, including dry scrubbers and selective catalytic reduction. This coal-fired plant forms part of MidAmerican's portfolio of diverse generation resources, which includes wind, biomass, nuclear, hydro, natural gas, oil and coal. Phase 1 of a 540 MWe natural gas-fueled generation station has been completed in Pleasant Hill, Iowa, and plans have been announced for the construction of 310 MWe of wind turbine generators in north central Iowa. To be acceptable, the coal-fired plant was required to be cleaner and more efficient than previous units, so that MidAmerican opted for state-of-the-art technology. The steam conditions have not been announced, but the temperature of the steam delivered to the high-pressure turbine is believed to be no higher than 580°C which, while somewhat higher that the norm for current supercritical steam plants in the US (540-565°C), is still well below that of the state-of-the-art plants now in service in Europe and elsewhere of 600-610°C. Hitachi Ltd. of Japan is providing boilers, power turbines and other critical technology expertise, and Mitsui & Company is responsible for managing the construction. Sargent & Lundy, Chicago, is the design engineer, and Kvaerner Songer from Washington, Pa., serves as the general work contractor.

From: MidAmerican Energy's Fact Sheet, 9/9/03. For more information, contact: Allan Urlis , Director of Media Relations, MidAmerican Energy Company; 'phone: 515.281.2785.

H-System Turbine Award

Power Engineering magazine has picked the H-System Gas Turbine at the Baglan Bay Power Station near Cardiff, Wales as one of its top three power projects in 2003. The H-System gas turbine is the product of a jointly funded development effort between GE Power Systems and the U.S. Department of Energy's Office of Fossil Energy. The increased performance in terms of efficiency and emissions (9 ppm NO_x) of this turbine rely heavily of on the use of advanced materials and a new steam-cooling system that allows operation at firing temperatures of 1427°C/2600°F. For more information, contact: David Anna, DOE's National Energy Technology Laboratory, 'phone: 412.386.4646; e-mail: anna@netl.doe.gov.

Coal Mine Methane Fuel Cell in Ohio

FuelCell Energy of Danbury, Conn., has started operation of a 200-kW Direct FuelCell® technology fuel cell powered by coal mine methane in a six-month demonstration at the Rose Valley coal mine methane test site in Hopedale, Ohio. Direct FuelCell® power plants can use hydrocarbon fuels to produce electricity without the need to first create hydrogen in an external fuel processor. Because hydrogen is generated directly within the fuel cell module from readily-available fuels (in this case, coal mine methane) these power plants do not require the creation of an extensive hydrogen supply infrastructure. The National Energy Technology Laboratory, the research laboratory for the Department of Energy's Office of Fossil Energy, is managing The overall three-year project is managed by the National Energy Technology Laboratory; the total cost of the project is approximately $7m, shared equally between the Department of Energy and FuelCell Energy. For details, contact: David J. Anna, DOE National Energy Technology Laboratory, 412-386-4646, david.anna@netl.doe.gov

Sensor Research Projects Selected

As a result of the solicitation "Development of Novel Sensors for Ultra High-Temperature Fossil Fuel Applications," the Department of Energy's National Energy Technology Laboratory (NETL) has selected three projects to develop sensors that will operate in high-temperature, harsh environments. The awards are being made from the Instrumentation, Sensors and Control System program, a part of NETL's Advanced Research Program, which targets novel research opportunities for fossil-energy systems. The awards are:

Nuonics, Inc., Orlando, Florida will develop an ultra high-temperature-resistant and vibration-tolerant sensor based on SiC. The sensor will be able to accurately measure temperature, pressure, and concentrations of combustion materials using interferometry. The refractive index changes in SiC due to changes in the system temperature and pressure will be measured by a high-speed remote-detection system. Nuonics will also study the feasibility of detecting gas species by coating the silicon carbide materials. The value of the award is $950,000, and the project duration is 36 months.

Prime Research, L.L.C., Blacksburg, Virginia will develop sensors based on sapphire fibers that have been altered to deliver a single wavelength or multiple wavelengths of light. The highly sensitive, ultra-high-temperature micro-sensors will be used in the control systems of next-generation zero-emission fossil-fuel power plants. The feasibility of this technology was recently discovered, and focuses on measurements and sensors that are most likely to survive in the harsh environments of fossil-energy power plants. Prime Research will fully develop the process to produce these special fibers. The value of the award is $945,186 (Prime Research Share: $38,994), and the project duration is 36 months.

SRI International of Menlo Park, California will develop an arrangement of miniature solid-state, electrochemical sensors that are inexpensive, rugged, reliable, and easy to fabricate. The sensors will measure the concentration of nitrogen oxides, sulfur oxides, and hydrocarbons, and they will be able to operate in high-temperature and high-pressure environments using a novel array and packaging design. This novel design will serve as a basis for integrating micro-sensors into next-generation power plants because current sensor technologies are inadequate for online monitoring of emissions. The value of the award is $641,820, and the project duration is 36 months.
For more information, contact: David J. Anna, DOE NETL, 'phone: 412.386.4646; e-mail: david.anna@netl.doe.gov, or Susan Maley, DOE NETL, 'phone: 304.285.1321; e-mail: susan.maley@netl.doe.gov

DOE to Test Advanced Methods For Reducing Mercury Emissions

With coal-burning utilities facing the prospect of first-time control on mercury emissions, the Department of Energy has selected eight new projects to test mercury control technologies at coal-fired power plants. The selections build on past DOE research and focus on longer-term, large-scale tests of the most promising mercury control technologies at a broader range of utility field-test sites, specifically those burning lignite, and those with smaller electrostatic precipitators. These pre-commercial demonstration tests will be conducted at commercial coal-fired power plants and will produce information on mercury removal effectiveness and cost, and the potential impacts on plant operations. The eight projects were selected are:

ADA Environmental Solutions, LLC, Littleton, Colorado will evaluate the use of sorbent injection to remove mercury from coal-combustion gases in conjunction with existing pollution-control equipment. Full-scale sorbent-injection equipment will be installed and tested at four power plants that cover a combination of coals and pollution control equipment that are representative of 78 percent of existing coal-fired generation and a large portion of new plants. The research team also includes EPRI, CONSOL, Reaction Engineering, and Microbeam Technologies.

ADA Technologies, Inc., Littleton, Colorado will test a new non-carbon sorbent (Amended Silicates^{TM}) that delivers high mercury removal levels while avoiding impacts on fly ash sales. The project will take place at a 75-MW unit operated by Cinergy Power Generation Services in Miami Fort (Unit 6). The project team also includes the University of North Dakota and Western Kentucky University.

URS Group, Inc., Austin, Texas will inject sorbents upstream of a small collection-area electrostatic precipitator (ESP), followed by a wet scrubber at Southern Company Services' Plant Yates (Unit 1) in Atlanta, GA. Previous full-scale sorbent injection tests have involved relatively large ESPs, but more than 60 percent of the industry is equipped with ESPs having small-size collection areas. The tests will evaluate longer-term removal performance and by-product quality. Other team members include ADA Environmental Solutions and EPRI.

URS Group, Inc., Austin, Texas. This project involves large-scale testing of a honeycomb catalyst system that has been shown to be effective in oxidizing elemental mercury so that it can be removed in downstream wet lime or limestone flue gas desulfurization (FGD) systems. Testing will be conducted over 14 months at two stations: TXU Monticello Station, and Duke Energy's Marshall Station. One plant burns Texas lignite, and the other a low-sulfur bituminous coal. Both are equipped with an ESP and wet scrubber.

URS Group, Inc., Austin, Texas will test EPRI's Mercury Control via Adsorption Process (MerCAPTM) technology for controlling mercury emissions from coal-fired power plants. The process involves placing a regenerable, fixed-structure sorbent into a coal flue gas stream to remove mercury. Because the sorbent periodically regenerates as it captures and isolates mercury for disposal, mercury will not be contained in the combustion by-products. Testing will occur over a 6-month period at Great River Energy's lignite-fired Stanton Station, and at Southern Company Services' bituminous-fired Plant Yates.

University of North Dakota, Grand Forks, North Dakota. This project focuses on enhancing the effectiveness of activated carbon in capturing mercury in plants burning low-rank lignite coals. Because of low chlorine and high calcium content, lignite produces higher levels of elemental mercury, which is more difficult to remove. Two different approaches will be evaluated: the injection of chlorine-based additives and the use of chemically treated sorbents. Testing will be performed on four units at three power plants burning North Dakota lignite: Leland Olds Station (Unit 1) and Stanton Station (Unit 10), both near Stanton, ND; Antelope Valley Station (Unit 1) near Beulah, ND. Two units are equipped with ESPs only, and two are equipped with spray dryer absorbers combined with fabric filters.

University of North Dakota, Grand Forks, North Dakota will evaluate the effectiveness of using a chloride-based additive to increase mercury oxidation upstream of an ESP and a wet scrubber at two lignite-burning plants. The host sites include Minnkota Power Cooperative's Milton R. Young (Unit 2) in North Dakota, and TXU Monticello (Unit 3) in Texas. The project will measure mercury oxidation levels removal rates across existing ESP and FGD units; determine costs associated with those removal rates; investigate the possibility of the air pollution control device acting as a multi-pollutant control device; and quantify plant maintenance impacts due to the control approach.

Sorbent Technologies Corp., Twinsburg, Ohio will test a novel sorbent at Duke Energy's Buck Station or Allen Station, which are both equipped with an ESP and burn bituminous coal; and also at Detroit Edison's St. Clair Station, which burns a mixture of bituminous and sub-bituminous coal. Other program participants are; Duke Power; Detroit Edison; Fuel Tech, Western Kentucky University's Combustion Laboratory; PS Analytical; Spectra Gases; and Stock Equipment Company.

For more information, contact: David Anna, DOE NETL, 'phone: 412.386.4646; e-mail: david.anna@netl.doe.gov

Meetings Calendar

February 16, 2004: A Technical Workshop on *Near-Term Options to Reduce CO_2 Emissions from the Electric Power Generation Sector in APEC Economies* will be held at the Conrad Jupiters Convention Centre, Gold Coast, Queensland, Australia in conjunction with the IEA Asia Pacific Conference on *Zero Emissions Technologies* (February 17-19, 2004). The workshop will address the following topics: upgrading and refurbishment of existing power plants; efficiency improvements in existing power plants; fuel switching for emission reductions; new commercial generating technologies (supercritical and ultra-supercritical pulverized coal, integrated gasification combined cycle, gas turbines, fuel cells, etc.) including their market penetration, economics, reliability, O&M, and other related issues; emission accounting and trading schemes, and development co-operation; and facilitating trade and investment in APEC developing economies in areas relating to CO2 emission reduction from electricity generation. For additional details, contact: NETL Conference Services Information, NETL Event Management, National Energy Technology Laboratory; 'phone: 412.386.6044; fax: 412.386.4604; e-mail: kimberly.yavorsky@netl.doe.gov

March 7-10, 2004: The *First International Conference on Fuel Cell Development and Deployment*, University of Connecticut, Storrs, Connecticut. For information, contact: Laurie Enderle, School of Engineering, 261 Glennbrook Road, Unit 2237, University of Connecticut, Storrs, CT 06269-2237; 'phone: 860.486.3295; fax: 860.486.2269; or e-mail: ctfuelcell@engr.uconn.edu.; website www.ctfuelcell.uconn. edu/scic/. See Materials & Components No. 160.

March 28-April 1, 2004: NACE's 59th Annual Conference & Exposition—CORROSION NACExpo 2004—will be held at the New Orleans Conference Center and the New Orleans Marriott, New Orleans, Louisiana. The Specific Technology Group for Energy Generation (STG41) will hold a symposium on advances in materials and corrosion control in fossil fuels conversion and combustion, as well as a panel discussion on materials selection and performance in incinerators and waste fuel facilities. For details, contact: Larry Paul, ThyssenKrupp VDM USA Inc., Tipton, Indiana; 'phone: 765.675.9964; fax: 765.675.9836; or e-mail: lpaul@tiptontel.com.

April 18-22, 2004: The *29th International Technical Conference on Coal Utilization and Fuel Systems*, Sheraton Sand Key Hotel, Clearwater, Florida. Information is available from: Barbara A. Sakkestad, Coal Technology Association, 601 Suffield Drive, Gaithersburg, MD 20878; 'phone: 301.294.6080; fax: 301.294.7480; website www.coaltechnologies.com. See Materials & Components No. 160 (calls for papers).

April 19-23, 2004: The *International Conference on Metallurgical Coatings and Thin Film*s, Town and Country Hotel, San Diego, California. For information see the conference website at http://www.abs.org/conferences/icmctf/coal. See Materials & Components No. 160.

May 16-21, 2004: The sixth *International Symposium of High-Temperature Corrosion and Protection of Materials* will be held on the Ile des Embiez, France. This conference is intended to permit open, in-depth discussions and exchanges on the various scientific and technical aspects of corrosion of materials at high temperatures under the joint action of temperature, multi-oxidant chemical and mechanical environments, and of specific parameters representative of their conditions of use. The main themes of the symposium are: 1. *The Main Industrial Fields Concerned With High-Temperature Corrosion*: land-based gas turbines, diesel engines; boilers, incinerators, burners; coal gasification; aerospace industry; fuel cells; exhaust systems and high-temperature filtration/hot gas clean up; and high-temperature processes in industry (chemical, petrochemical, steelmaking, glassmaking, pulp and paper industries). 2. *Advanced Materials And Associated Problems Concerned With High-Temperature Corrosion*: development in understanding of high-temperature corrosion and protection in aggressive environments; high-temperature coatings (including thermal barrier coatings); high-temperature alloys and intermetallics; ceramics and composites; metal dusting and carburisation; role of water vapour and steam on high-temperature corrosion; modeling and lifetime prediction; spalling and mechanical aspects; and advanced characterisation techniques of degradation. For details, contact: Prof. P. Steinmetz, Université de Nancy, psteinme@persmail.uhp-nancy.fr; Ian Wright, Oak Ridge National Laboratory: wrightig@ornl.gov; or visit the web site at: http://www.htcpm-2004.uhp-nancy.fr.

June 14-17, 2004: The 49th ASME TurboExpo-Power for Land, Sea & Air will be held in the Austria Centre, Vienna, Austria. The program includes sessions on: biomass gasification; combustion of alternative fuels; treatment and technologies to enable the use of solid fuels in gas turbines; advanced systems for coal utilization; new concepts for reduced CO_2 emissions; status of large-frame gas turbines; condition monitoring of large utility plants; repair and manufacturing technology; degradation and life prediction; and advanced in high-temperature coatings. For further information, contact: IGTI
5775-C Glenridge Drive, Suite 115, Atlanta, Georgia 30328; 'phone: 404.847.0072; or fax: 404.847.0151.

July 7-9, 2004: The *17th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy and Process Systems (ECOS)*, Guanajuato, Mexico. The conference has a home page at: http://ecos2004.imp.mx. See Materials & Components No. 160 (calls for papers).

July 28-30, 2004: The *Coal-Gen 2004 Conference* will be held at the Overland Park Convention Center, Overland Park, Kansas. The issues of interest at this conference include: design, development, construction, upgrading, operation and maintenance of coal-fired power plant. The major themes will be: *Existing Asset Value Maximization* (including fuel and materials handling; boiler operation and maintenance; steam turbine upgrades; balance of plant equipment issues; plant cooling/water treatment; re-powering); *Environmental Issues*; *New Generation* (including plant siting; boiler technology; integrated gasification combined cycle; fluidized-bed combustion; next-generation coal-fired power plants; alternative fuels: waste coal and petcoke; supercritical and ultra supercritical steam cycles); and *Coal Supply & Materials Handling*. For details, contact: Jan Simpson, PennWell Corporation, 1421 S. Sheridan Road, Tulsa, OK 74112; 'phone 918.831.9736. The conference has a web site at: coalgenconference@pennwell.com

October 5-7, 2004: *Power-Gen Asia 2004* will be held at the Impact Exhibition and Convention Center, Bangkok, Thailand. For more information, contact: Miss Seoniad Thomas, 'phone: 011.44.199.265.6629; fax: 011.44.199.265.6704; or e-mail: powergenasia@pennwell.com.

October 20-22, 2004: Stainless Steel World-American 2004 Conference held at the Doubletree Hotel, Houston, Texas. Plenary paper and workshop sessions will be held on such topics as clad materials, weld overlay, risk-based inspection, failure analysis, welding, and high-temperature applications. The conference will extensively cover the following materials groups: duplex and super duplex stainless steels: super martensitic stainless steels; austenitics and super austenitics; other stainless steels; Ni-based alloys; titanium; and other corrosion-resistant metals. For further information contact Mrs. Marion Barth at ssw-America@kci-world.com. The conference also has a website at www.stainless-steel-world.net.

November 1-4, 2004: The *2004 International Gas Research Conference*, Vancouver Conference Centre, Vancouver, British Columbia, Canada. For information, contact Christopher Esson, 1700 South Mount Prospect Road, Des Plaines, Il 60018-1804; 'phone: 847.768.0816; fax: 847.768.0842; e-mail: igrc2004@gastechnology.org.; website www.igrc2004.org. See Materials & Components No. 160.

November 17, 2004: The U.S. Department of Energy's (DOE) Office of Fossil Energy's *Clean Coal and Power Conference*, and the *2nd Joint U.S.-People's Republic of China Conference on Clean Energy* (November 18-19), Ronald Reagan International Trade Center in Washington, D.C. For information contact: Faith Cline, 'phone: 202.586.7920; fax: 202.586.0734; or e-mail: faith.cline@hq.doe.gov.; website: http://fossil.energy.gov/news/events/cleancoal/index.html. See Materials & Components No. 160.

Calls for Papers

April 29-30, 2004: The second international; conference on Industrial gas Turbine technologies, organized by the Thematic network CAME-GT of the European Union's RTD Framework Programme V will be held at Hotel Golf, Bled, Slovenia. The deadline for submission of Abstracts is 2/2/04 and papers 29/3/04.

June 11-12, 2004: A US-China Industrial Boilers Workshop: "Increasing Energy Efficiency, Reducing Pollution and Greenhouse gases," will be held in Beijing, Peoples Republic of China.

October 27-29, 2004: A workshop on *Novel Approaches to the Improvement of High-Temperature Corrosion Resistance* will be held at DECHEMA House, Frankfurt am Main, Germany. This will be European Federation of Corrosion Event No. 275. The major topics of the Workshop are expected to be: alloy modification; surface treatment; test methods and service conditions; and modeling. Since four large European joint research efforts will be close to completion at that time (COTEST-code of practice for cyclic oxidation testing; OPTICORR—modeling of high-temperature corrosion for optimization of service performance of boilers steels; SMILER—surface-treated materials for improved life and emissions reduction; and SUNASPO—surface engineering of new alloys for super high-efficiency power generation), it is expected that there will also be discussion of results from these efforts at the Workshop. Abstracts should be submitted before march 31, 2004 to: Prof. Michael Schütze, DECHEMA, Karl-Winnaker-Institut, Theodor-Heusse-Allee 25, D-60486 Frankfurt am Main, Germany; 'phone: 011.49.69.756.4361; fax: 011.49.69.756.4388; e-mail schuetze@dechema.de. The Workshop also has a web site at: www.dechema.de/efcws04.

A Word From Our Sponsor...

Please note that the *4th EPRI/DOE International Conference on Advances in Materials Technology for Fossil Power Plants* will be held at the Hilton Ocean Front Resort, Hilton Head Island, South Carolina on October 26-28, 2004. Presentations will be made by worldwide utilities, equipment manufactures, alloy venders, forging shops, casting houses, universities, national labs, and consulting and research organizations on subjects that will include: plant economics; new materials development concepts; high-temperatures materials used in boilers and turbines in steam power plants; ferritic steels, austenitic steels, and nickel-based alloys; boiler tubes, headers, steam pipes, water walls; turbine rotors, blades, bolts, casings, valves, and high-temperature components. The issues to be addressed include creep; fatigue; toughness; corrosion; weldability; fabricability; coating and claddings; microstructures; advances in design; and field experience. Abstracts should be submitted by March 14, 2004 to: Melissa Wade, EPRI, 1300 W. T. Harris Boulevard, Charlotte, NC 28262; ‘phone: 704.547.6176; fax: 704.547.6109; or e-mail: melwade@epri.com.

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