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crucible induction melting. Also the VAR process and plasma arc cold hearth melting (PACHM) process have been used to melt titanium aluminides as well as MoSi$_2$. Many applications of intermetallics require cast components. Casting methods include sand, investment, centrifugal, directional solidification, and near net shape methods.

Fine-grain wrought products are required in other applications. The commercial use of intermetallics at competitive cost requires fabrication by conventional hot working operations. The primary processing of cast ingots is feasible, but the requirement for hot working is more stringent than for commercial metallic alloys. The secondary processing of intermetallics is very difficult and varies from intermetallic to intermetallic.

Powder metallurgy offers the most flexibility in producing intermetallics. The problem of using powder metallurgy for this purpose is that these production methods often result in surface contamination of the powders. Each of the powder consolidation methods for producing intermetallics from powders has processing difficulties. These methods are hot pressing, hot isostatic pressing, powder injection molding, extrusion, and explosive compaction. The reaction synthesis process has been uniquely applicable for intermetallics and has been used to produce many different materials.

Secondary processing. Secondary steps such as machining and joining are critical in using these advanced materials for various applications, and extensive efforts are under way to develop these technologies. Innovative joining techniques such as friction welding, capacitor discharge welding, flash welding, laser welding, welding using the combustion synthesis concept, welding using microwaves and infrared waves, electron-beam welding, brazing, and diffusion bonding are under evaluation. A variety of machining techniques, including electrodischarge machining, water-jet cutting, ultrasonic machining, and laser cutting, are available to precision-machine complex geometries and contours. Conventional grinding, diamond drilling, and boring techniques have seen limited applications in machining TiAl alloys.

Intermetallic matrix composites. Intermetallic matrix composites have recently received considerable attention, and a variety of matrices and reinforcements have been examined to date. Reinforcement type, volume fraction, size, shape, and distribution have been shown to affect microstructure and mechanical properties. Several innovative approaches ranging from conventional techniques, such as mechanical alloying, to more exotic techniques, such as reactive consolidation and magnetron sputtering, have been used to produce these composites. Process models are being formulated and coupled with state-of-the-art sensors technology to optimize parameters to produce composite materials of high integrity.

Issues related to reinforcement selection include availability, mismatch in thermal expansion coefficients, and chemical compatibility with the matrix. Significant advances in characterization have been made in continuously reinforced Ti$_3$Al-based alloys (SiC fibers in Ti$_3$Al + Nb alloys) and particulate-reinforced TiAl alloys (TiAl + TiB$_2$ particulates), in directionally solidified (DS) eutectics of NiAl, and in discontinuously reinforced MoSi$_2$. In most cases, the major emphasis has been on obtaining a desirable balance between creep resistance and low-temperature fracture toughness. In this endeavor, micromechanical modeling has been used to identify, understand, and quantify the critical material parameters that control these properties, thereby permitting microstructural design to obtain the desired combinations of these properties. Potential areas for future research include the need for viable machining and joining techniques and novel but reliable nondestructive evaluation methods.

For background information *SEE ALLOY; CERMET; COMPOSITE MATERIAL; CRYSTAL STRUCTURE; HIGH-TEMPERATURE MATERIALS; INTERMETALLIC COMPOUNDS; WELDING AND CUTTING OF METALS* in the McGraw-Hill Encyclopedia of Science & Technology.

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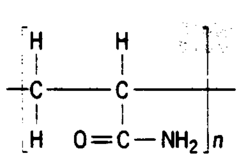
Irrigation (agriculture)

Agricultural erosion research has focused primarily on rainfall-induced soil loss, but erosion losses associated with surface irrigation practices can be equally severe. Of the estimated 2.5 × 10^8 hectares (6 × 10^8 acres) irrigated worldwide, at least 60% are surface irrigated. In the Pacific Northwest, approximately 1.5 × 10^6 ha (3.7 × 10^6 acres) of the most erosive soils in the United States are surface irrigated. Typically, 5.5–55 tons of soil per hectare per year (5–50 metric tons per acre per year) can be lost from furrow-irrigated fields, and three times that amount from near the furrow inlets at the upper end of fields.

Soil erosion. Soil erosion is highly detrimental, both on- and offsite. Furrow erosion can be reduced effectively by using various approaches, including settling ponds, minibasins with buried-pipe runoff control, furrow straw mulching, and sodded furrows. However, farmers have resisted using these alternatives for various reasons. In some cases, the techniques cannot be conveniently incorporated into existing farm plans: in others, the philosophical or economic inducements are not great enough to stimulate the additional effort. If erosion control is to be more uniformly implemented, farmers require simple and economical erosion prevention thod that permits them to use familiar tillage and op cultural practices. New technology employing ter-soluble polymers may provide such a method. e technique involves the application of 10 liter (0.0013 oz/gal; 10 parts per million) of polyylamide polymer to the furrow irrigation stream. ptimal anionic-polyacrylamide applications have duced mean soil loss from furrow-irrigated fields % (80–99%), while net water infiltration into soil creased 15%. Treatment with polyacrylamide also proves furrow tailwater (surface runoff) quality decreasing levels of phosphorus, nitrate, and biochemical oxygen demand.

Water-soluble polyacrylamide. The most successl polymer to date is a water-soluble anionic rganic compound known as polyacrylamide (PAM). Anionic polyacrylamide is composed of 0,000 or more three-carbon molecular units linked into a single linear chain. Of the repeating units, 2% have the structure below. The remaining 18%


$$\left[-CH_2-CH(C(=O)-NH_2)-\right]_n$$

are similar, except the —NH_2 group is replaced by a —[ONa] ionic pair. This pair dissociates upon dissolution, giving the polymer a moderate negative charge. The properties that enable polyacrylamide to prevent soil erosion are its ionic charge type and density, water solubility, and very high molecular weight (5–15 × 10^6 g mol^{-1}).

The ability of polymer manufacturers to synthesize polyacrylamides with increasingly more effective configurations and properties has improved significantly since their introduction to agriculture as soil-stabilizing amendments in the mid-1940s. Historically, polymers were spread in the field and incorporated into the plow layer with tillage. The resulting well-aggregated field surface was significantly more resistant to raindrop impact and concentrated flow, which tend to break down soil aggregates, detaching soil particles, reducing infiltration, and increasing runoff and erosion. Unfortunately the polymer application rates (250–500 kg/ha or 220–450 lb/acre) required to obtain acceptable results were not cost effective. New polymer technologies apply only 0.5–3 kg/ha (0.45–2.7 lb/acre) polyacrylamide per application. At projected prices of $6.50–11.00 per kg, and total seasonal applications of 1–7 kg/ha (0.9–6 lb/acre), polyacrylamide can be economical for all but the lowest-valued irrigated crops. Although new polyacrylamides are actually more effective agents, additional efficiency of the current polyacrylamide application technology results because polymer is applied in the irrigation water. Hence, only that part of the soil surface subject to erosive and seal-forming processes is treated (that is, the wetted furrow perimeter).

Environmental safety. At concentrations used in field application, anionic polyacrylamide is benign, having little or no toxic effect on humans and other mammals, aquatic vertebrates and invertebrates, or plant life. In the United States it has been listed by the Environmental Protection Agency as an acceptable drinking water additive and has gained a variety of approvals by the Food and Drug Administration for food additive applications. In soil, polyacrylamide acts like other naturally occurring, persistent forms of organic matter, degrading to water and carbon dioxide at a rate of approximately 10% per year. At higher rates of polyacrylamide application to soils (>25 mg/kg or 0.0033 oz/lb), research has shown some impacts on soil microorganism populations, although results have not been consistent or pronounced in the studies that have been completed. Much of the current research on polyacrylamide-amended irrigation water seeks to better understand its potential short- and long-term impacts in soil and aquatic systems.

In the United States, by law manufacturers must market only pure polyacrylamide products. The main concern is the manufacturing contaminant, acrylamide monomer, a known toxin. Its concentration in marketed anionic polyacrylamide is strictly regulated (<0.05%). At these levels, acrylamide monomer is of little concern in soils or surface waters because it rapidly biodegrades, decomposing in a matter of days.

Soil interactions. The basis of polyacrylamide's erosion control ability is its propensity to bind with both soil particles and other polyacrylamide molecules. In dilute solution, strands of anionic polyacrylamide polymers exist as random coils. When a strand collides with a soil particle, several segments of the coil become adsorbed to the particle surface. The polymer is held to the surface at numerous points along the contacting segments by any one of several forces, which include electrostatic attraction, hydrogen bonding, van der Waals forces, and chemical bonding. Cation bridging is an important form of electrostatic bonding associated with anionic polyacrylamide. Here, a divalent cation [such as the calcium ion (Ca^{2+})] acts as a positively charged bridge between the negatively charged site on a soil particle and a negatively charged site on the anionic polyacrylamide segment. Because bonding occurs at several locations along the particle/polymer-segment contact, the attraction between the two is very strong and essentially irreversible. A significant fraction of the polymer segments are not in contact with the particle, but extend into the solution. The nonadsorbed segments may then come into contact with, and become adsorbed to, other soil particles. They may also contact another polymer strand, and become either entangled or linked together by cation bridging or hydrogen bonding. These interactions facilitate polyacrylamide's soil stabilizing and flocculating activity during furrow irrigation. When soil colloids suspended in a polyacrylamide solution collide, polymer strands help bind the particles together in flocs. These flocs encounter and bind to other particles. The aggregating masses rapidly become so large that they settle out of suspension by a process known as flocculation.

Furrow irrigation processes. Furrow erosion is controlled by two main factors, furrow stream hydraulics and soil characteristics. Velocity of the flow determines the amount of shear or drag forces available to detach soil particles. Velocity also determines the flow's sediment transport capacity, which along with sediment/aggregate size and density characteristics determines the amount of detached soil that can be transported down the furrow. The soil characteristics aggregate stability and soil cohesion determine to what degree soils are susceptible to flow shear force, and they also control the characteristics of sediment and aggregate size distribution.

To understand how polyacrylamide acts to control erosion, it is necessary first to consider the effects of rapid wetting and flow shear during irrigation of an erodible soil. Prior to irrigation of a newly cultivated furrow, soils are typically very dry and cloddy, and the surface quite rough. Rapidly advancing water is quickly absorbed by soil, causing aggregates to slake and soil particles to disperse. Flow shear easily detaches dispersed soil particles and transports them down the furrow. The rough surface of the wetted furrow is smoothed as soil clods break down. Dislodged soil particles then fill surface cavities along the furrow perimeter. This smoothing increases the velocity and erosiveness of the furrow stream. Initially, infiltration is high and flow rate is low. Infiltrating water soon carries flow-suspended sediment into the soil, where it blocks soil pores and initiates formation of a slowly permeable depositional layer, or surface seal. The seal reduces infiltration, and as a consequence runoff and soil losses increase.

The introduction of polyacrylamide into irrigation water, even at low concentrations, has several impacts on furrow conditions. During initial wetting, polyacrylamide contacts and binds a 1–3-mm-thick (0.04–0.12-in.) layer of soil on the surface of furrow clods and along the wetted furrow perimeter. Treated soil is more cohesive and stable, that is, more resistant to slaking, dispersion, and shear forces. Any fine soil particles in the furrow stream are flocculated and settle as aggregates. Together these processes produce a well-aggregated system. Consequently, surface roughness in the furrow is better maintained, and the depositional layer formed along the wetted perimeter is more porous. Thus, infiltration rates remain high and runoff rates are lower, and soil detachment is inhibited. Sediment transport capacity of the flow is also reduced, because stream velocity is lower and the average aggregate in the system is larger and less easily transported. Polyacrylamide may also increase viscosity of flowing water, resulting in lower turbulence and smaller shear forces.

Application strategies. The mode of polyacrylamide application can be altered simply by (1) varying polyacrylamide concentration in the irrigation water; (2) changing the timing of application (at beginning of irrigation, only intermittently, or continuously); (3) adjusting the length of application period relative to the time required for water to initially traverse the dry furrow (furrow advance time); or (4) changing the form of polyacrylamide added to irrigation water (aqueous stock solution versus a directly introduced crystalline solid). For example, an initial high strategy applies a high dose of polyacrylamide only during early stages of an irrigation. An initial episodic strategy applies polyacrylamide intermittently during the entire irrigation, but dosage rates are lower and individual application periods are shorter compared to the initial high strategy. Another strategy is the continuous low, where polyacrylamide is applied throughout the irrigation but at very low concentration.

Initial high and initial episodic strategies are equally effective at controlling furrow soil loss in the initial treated irrigation, even though the total polyacrylamide applied for initial episodic was 50% of that applied for initial high. When initial high and continuous low strategies were compared, it was found that the continuous low treatment did not protect the furrow from the high loss of loose and easily detached soil particles that typically occurs early in an irrigation: as the irrigation proceeded, the more stable soils remaining in the furrow were more successfully protected. In contrast, the initial high treatment protected both loose and cohesive soil, and was clearly the more effective treatment for the given conditions. Compared to control furrows, it reduced soil loss by 93%, in contrast to a 51% reduction for the continuous low application. A continuous or intermittent application strategy may be more effective under circumstances in which flow shear is relatively high (for example, steeper slopes or high flow rates).

The initial high strategy is recommended, because it has been shown effective for a variety of soils and slopes. If polyacrylamide application is restricted to the furrow advance period, this method also minimizes the amount of polyacrylamide lost in tailwater. (During a 10 mg/liter or 0.0013 oz/gal polyacrylamide application, tailwater contains an average 5–7 mg/liter or 0.0007–0.0009 oz/gal of polyacrylamide.) Although the initial episodic strategy may possibly be as effective, it has not been as thoroughly tested, and may be more difficult to implement in actual farming situations. Preliminary studies comparing initial high, polyacrylamide solution and solid applications (10 mg/liter or 0.0013 oz/gal) indicate that they control soil loss equally well. The advantages and disadvantages of these methods are listed in the **table**.

Research has shown that anionic polyacrylamide technology successfully controls furrow irrigation–induced soil loss under a variety of circumstances: however, efficacy of polyacrylamide [illegible] solution and solid polyacrylamide application methods

		Total polyacrylamide employed		Polyacrylamide [illegible]	
[illegible]	Erosion control efficacy	Volume applied	[illegible] applied	Concentration	[illegible]
[illegible]	Excellent	Large	[illegible]	Excellent	[illegible]
[illegible]	Excellent	Small	Small	Poor	[illegible]

[illegible] Ability to make timely [illegible] polyacrylamide concentration in irrigation water.

atments has been shown to vary among irriga- ns. The effectiveness of polyacrylamide treat- nts is influenced by the properties of the olymer, the characteristics of polyacrylamide plication and of the field under treatment, the ture of irrigation and irrigation water, and the hemical and physical soil characteristics.

Further research is needed to determine how factors such as furrow soil properties, slope length, and inflow water quality influence anionic polyacrylamide efficacy in irrigated furrows.

For background information *SEE* EROSION; IRRIGATION (AGRICULTURE); POLYMER; SOIL in the McGraw-Hill Encyclopedia of Science & Technology.

Rodrick D. Lentz

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Laser

Ultrashort pulsed lasers, which generate light pulses between 1 femtosecond (10^{-15} s) and 1 picosecond (10^{-12} s) in duration, have found a variety of applications in engineering, chemistry, and physics. Light pulses from these sources can be manipulated to provide time-resolved measurements of ultrafast events, such as photochemical reactions, charge-carrier dynamics in semiconductors, or microcircuit response times; these events occur in a time regime well beyond the capabilities of conventional electronic instruments such as pulse generators and oscilloscopes. The technology of ultrashort laser pulse generation and manipulation will be examined and current applications discussed.

Ultrashort light pulses. Traditional measurements of fast dynamical events are performed by using high-speed electronic instrumentation such as oscilloscopes and transient digitizers. This instrumentation has evolved dramatically, yielding subnanosecond ($<10^{-9}$ s) performance. However, advances in laser technology have enabled the routine generation of optical pulses with durations on the order of 10 fs. The terminology ultrafast and ultrashort is used to refer to optical pulse durations or physical phenomena which fall in the femtosecond to picosecond time regime.

The generation of ultrashort laser pulses is made possible by mode locking. This technique is achieved by a device which modulates the loss (or gain) in a laser cavity in the time period required for a pulse to complete one round trip within a cavity of length L (**Fig. 1**). The effective generation of very short duration optical pulses requires that the laser cavity and gain medium be capable of supporting several thousand longitudinal cavity modes whose optical frequencies are separated by $\Delta f = c/(2L)$, where c is the speed of light. The combination of many oscillating laser modes and the synchronous modulation of cavity loss results in a locking together of the phases of the cavity modes such that discrete laser pulses are emitted at an interval equal to the cavity round-trip time of $2L/c$. The duration of these discrete pulses is inversely proportional to the number of longitudinal modes that are locked in constant relative phase. This mode-locking phenomenon provides a stable constructive and destructive interference between the otherwise randomly phased oscillating cavity modes, resulting in a discrete series of ultrashort optical pulses.

A dilemma arises concerning the measurement of ultrashort pulse durations. Typically, the temporal variation of laser output is monitored by means of electronic photodiodes connected to oscilloscopes, but conventional electronic instrumentation cannot measure a laser pulse of subpicosecond duration.

The technique of autocorrelation is utilized to infer information about such pulse widths. A short

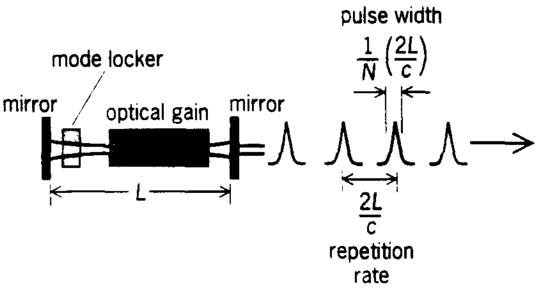

Fig. 1. Operation of mode-locked laser of cavity length, L, supporting N longitudinal cavity modes. c = speed of light.