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MECHANICAL DEBURRING
OF PLASTICS

PDO 6984314, Final Report

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**Kansas City
Division**

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MECHANICAL DEBURRING OF PLASTICS

BDX-613-988 (Rev.), UNCLASSIFIED Final Report, Published
January 1974

Prepared by R. J. Hishaw, D/835, under PDO 6984314

Hand deburring has been used to remove mold flash and machining burrs from relatively small parts molded from both thermosetting and thermoplastic resins. In an effort to reduce the time and manpower required for deburring, abrasive blast, flame, tumble, vibratory, slurry, putty extrusion, explosive, and cryogenic deburring were studied. Abrasive blasting was found to be the most efficacious and to have the broadest application. Tumble and vibratory deburring are effective on burrs on external surfaces.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

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SUMMARY

Machining burrs and mold flash have traditionally been removed from plastic parts by hand, using files, blades, drill bits, punches, and other instruments. These hand deburring methods are time consuming and non-repeatable, and many times result in damage to the parts. In a study to upgrade deburring at Bendix Kansas City Division, several methods were investigated: abrasive blasting, tumble deburring, vibratory deburring, explosive deburring, flame deburring, cryogenic deburring, slurry deburring, and putty extrusion.

The most successful of these has been abrasive blasting, both wet and dry. This development project was begun with the abrasive blasting phase, with emphasis on its use on numerous thermoset moldings with metal inserts. The major problem had been flash on these metallic inserts. The removal of this flash was time consuming when performed by hand and occasionally resulted in damage to the inserts. Establishing abrasive blasting processes has done much for the economic and expeditious production of these parts.

The tumble deburring phase of the project included barrel tumbler design and procurement, and acquisition of a tumbling mill from surplus equipment for tumbling small test quantities of parts. Studies were designed to evaluate the effects of this process on sharp features and surface finishes. The success of this method was found to be dependent on part size and geometry. Its major advantage over abrasive blasting is repeatability.

Vibratory deburring is quite similar in effect to tumble deburring in that an eroding effect is created between parts and the media in which they are submerged. The extent of this erosion is less than that during tumbling, in comparable amounts of time, making this process less effective in removing firmly attached burrs. It is also less likely to damage sharp part features. Both tumbling and vibrating are most effective on external surfaces.

Flame and explosive deburring techniques were investigated to determine the possibilities of using heat to melt away burrs on thermoplastics. Flame deburring showed some possible application on parts produced from low-melting-temperature resins when tight dimensional control is not mandatory. Explosive deburring showed degrading effects on all parts exposed. In addition, it tended not to remove burrs, but to leave them as undesired melted material.

Cryogenic deburring is not itself a deburring technique, but is used in conjunction with other methods. Because thermoplastic materials are known to increase in brittleness at lower temperatures, the use of cryogenic temperatures, in combination with either vibratory, tumbling, or abrasive blasting, will enhance the effect of burr removal. This approach has been somewhat successful with vibratory deburring.

When using cryogenics with abrasive blasting, another positive effect is gained. During dry blasting, friction between the abrasive and the part surface generates heat. If extensive blast time is necessary for complete burr removal, the heat may cause part warpage or dimensional change. This heat buildup could be controlled by cryogenic techniques rather than by controlling blast times.

Slurry and putty extrusion deburring studies were devoted exclusively to removing machining burrs from multi-hole product configurations. In both methods, an abrasive is suspended in a carrier and forced through the holes to abrade and fracture burrs. In the slurry deburring phase, carriers of water and various oils were used with different abrasive concentrations, and three generations of fixturing were developed for improvement in pressure capability, speed of operation, and directional control. The success of this process was limited by precipitation of abrasives, long cycle times, and inability to achieve high enough pressure and flow rates.

In the putty extrusion deburring phase, fixturing was developed to force an abrasive in a putty-like carrier through the drilled holes. This process increased the abrasive effects on burrs and flash in the hole areas, but required excessive cycling, operation time, and part cleanup.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this endeavor is to reduce the amount of manual labor and standard hours consumed in hand-deburring molded plastic parts by establishing more repetitive mechanical deburring processes. These processes are expected to ensure higher quality levels through repeatability. The scope of the project is to categorize burr or flash quantity and location, dimensional and visual considerations, and whether originating from molding or machining. Sizable reductions in part manufacturing costs will result from establishment and general use of such processes.

The justification for this endeavor lies in the extensive use of manual deburring methods on both thermoset and thermoplastic moldings. This type of deburring operation is time consuming and accounts for more than half of the consumed labor on many complex parts. It was determined that elaboration on existing deburring methods and development of methods conceived but uninvestigated would yield processes that would be less time consuming and more repeatable than hand deburring.

PRIOR WORK

The standard use of hand deburring methods has always been of concern. Either from an expense or process effects viewpoint, lack of repeatability and time consumption is undesirable. Some minimal work with sand blasting in non-critical areas had shown that plastic burrs would respond to such attacks.

Publications on metal deburring techniques revealed that such processes as explosive, thermal shock, and putty deburring had been effective in isolated cases but little information existed on applications to non-metallics.

A long-used process for thermoset deburring, commonly called Wheel-A-Brating®, is a combination of tumbling and vibrating parts in an abrasive media for exposed surface deburring. The resilience of most thermoplastic compounds made existing processes of this type ineffective for the degree of deburring desired for in-house applications.

ACTIVITY

Methods Investigated

Several techniques for mechanically removing burrs and flash from plastic moldings were investigated under this development project.

- Abrasive Blasting--Burrs are removed by exposing the part to bombardment by abrasive particles. These particles are propelled by air pressure and may be dry or suspended in water.
- Tumble Deburring--Burrs are removed by submerging the part in abrasive media inside a rotating container. The rotation of the container creates an action which flows the media over exposed surfaces of the part and abrades material from these surfaces.
- Vibratory Deburring--This process is similar to tumbling except that the shaking action of the vibrating container creates an eroding effect between the parts and media.
- Explosive Deburring--This process utilizes the energy of an explosion to remove burrs.
- Flame Deburring--This approach to deburring thermoplastic parts utilizes the low heat transfer properties of these materials. Exposing the entire part to an open flame of controlled intensity for a controlled period of time would, in theory, melt burrs and flash without damaging the part or altering dimensions.
- Cryogenic Deburring--This is not itself a deburring process but is used in conjunction with other processes. Theoretically, cryogenic temperatures will make burrs more brittle and susceptible to one of the other deburring processes.
- Slurry Deburring--This approach is oriented toward removing burrs from numerous holes simultaneously. The slurry is a combination of abrasive media and liquid. The part is fixtured so that this slurry can be forced through the holes under pressure. This, in theory, would create an abrasive action capable of removing burrs. By reversing the direction of flow at established intervals, a fatiguing effect would also be introduced, which would further aid in reducing the burr attachment.

- **Putty Extrusion Deburring**--This method is similar in effect to the slurry deburring technique, with increased pressure realized by suspending the abrasive media in a higher-viscosity, putty-like material.

It was considered that each process would be effective to some degree in specific applications; therefore, efforts were designed to identify the applications and degrees of effect that could be expected from each.

Abrasive Blasting

Thermosetting Plastics

Activity began with experiments in abrasive blasting processes for glass filled diallyl phthalate (DAP) parts with metallic inserts. It became evident in early testing that burrs and flash on this thermosetting material would respond readily to either wet or dry blasting at high pressure; however, part damage also resulted at these processing levels. It therefore became necessary to refine these blasting techniques. The parts chosen for study of this approach were a series of printed circuit board adapters which consisted of copper pins molded into DAP and protruding approximately 3/16 inch (0.48 cm). The problem area is on the pins themselves where plastic flash occurs and detracts from the conductive functions of inserts.

The variables in wet blasting were defined as follows:

- **Pressure**--The air pressure applied to media and carrier for blasting;
- **Time**--The period of bombardment or the time during which direct pressure is held on the part surface;
- **Distance**--The distance the nozzle is held from the part in process;
- **Angle**--The angle of blast approach to the surface in process;
- **Media**--The size and physical characteristics of the blasting media; and
- **Media-to-Carrier Ratio**--The concentration of abrasive dispersed in the flowing liquid and blast pattern. This ratio is dependent on both the amount of media added and the degree of agitation established.

The degree of abrasion of wet blasting was found to be adequate for deflashing DAP parts (Figure 1) regardless of age and degree of cure. Dry blasting

processes for diallyl phthalate parts were also investigated to fill a need for a less abrasive blasting method for deflashing parts having plated metal inserts. This is especially important in dealing with soft precious metals as used in the case molded assembly, a small DAP part with several gold plated pins protruding from the main body. The plating is 25 μ in. (635 μ m) thick. The use of hand deburring methods resulted in damage to this plating from direct contact with blades, abrasive balls, and various other hand deburring equipment.

Tests were performed to evaluate the plating removal that could be expected from dry blasting processes. The test included several runs to evaluate the effects of the variables as previously defined. Evaluation of plating thickness was a D-test; therefore, response was taken as deviation from specified thickness rather than actual change. Values of variables were derived that yielded flash-free parts without detectable damage to plating. It was also determined that this dry blast process was more effective in flash removal if performed soon after molding because of the relation of time to degree of cure in thermosets.

Thermoplastic Parts

Mold Flash. Dry blasting approaches to deburring thermoplastic parts were not as immediately successful as those for thermosetting plastics because of the resilience and toughness of thermoplastic burrs. Efforts were concentrated on parts molded of polycarbonate. These parts are rectangular moldings approximately 2.5 by 1.5 in. (6.35 by 3.81 cm) with thicknesses of approximately 0.080 in. (0.203 cm) and 0.180 in. (0.457 cm) respectively. Both parts have intricate hole patterns. The thicker of the two combines this hole pattern with counterbores.

Problem flash on these parts includes flash around small holes and edge flash. The several dry blasting techniques tried in this application were not successful in removing flash. Problems in dry blasting thermoplastics include peening, cold forming, and excessive heat buildup.

Peening is a surface effect seen on thermoplastic parts as a result of dry blasting. It is reflected as surface roughness and causes an increase in measurable thickness due to raised profile. It is enhanced by frictional heat resulting from the rapid collisions of particles with the part surface. This heat buildup softens the part surface, making the peening effect more pronounced.

Cold forming is the effect of bending tightly attached flash during blasting rather than removing it (Figure 2). The effects of such forming can be seen

Figure 1. Printed Circuit Board Adapter Before and After Deburring

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Figure 2. Cold Forming of Flash During Blasting
(Rolled Edge)

as dimensional changes in part features that indicate material has been added, such as smaller holes and increased external dimensions. Variables of blast angle and position affect this condition, but blast time is the major control. Again, heat buildup adds to the severity of this condition, and limited blast time decreases the amount of buildup; however, limited time also affects the extent of deflashing that can be expected.

Aside from the effects that frictional heat can have in conjunction with the aforementioned problems, excess heat in blasting thermoplastics can induce warp, causing loss of flatness or desired contour. The temperatures generated can also exceed the solidification point of polycarbonate and allow material flow to take place.

Machining Burrs. In applying wet blast deflashing processes to thermoplastics, a degree of abrasion near that seen in thermoset testing was not expected and, in fact, was not achieved. Initial testing was performed to determine the amount of material removal that could be expected. Sample blocks of molded polycarbonate were procured. These blocks were approximately 1 inch (2.5 cm) square by 0.25 inch (0.64 cm) thick. Several hundred of these samples were procured, and half of the samples were drilled through the center to a 3/8 inch (0.95 cm) diameter. Rough burrs were removed from edges and the parts were identified and accurately weighed.

The blasting study was then performed using several levels of the variables previously defined. After drying, the parts were again weighed. Comparisons of the two weighings gave the percentage weight loss from the blasting process; however, the weight change was not consistent, with the weight of some samples increasing after blasting. Few firm conclusions could be derived from this study. Apparently the weight loss was so small that other factors, such as moisture absorption, were overriding. It was determined that medium blasting pressures (30 to 60 psig [207 to 414 kPa]) were the most feasible for polycarbonate to avoid surface damage and to generate effective abrasion.

In applying the wet blast process to these parts, the increased abrasion from the liquid carrier and harder media aided in deburring effectiveness. The detrimental effects of dry blasting were seen but to a substantially lesser degree. It is felt that the reduction of heat buildup is mostly responsible for this improvement. The water carrier acts much as a coolant to reduce the rate and the magnitude of heat buildup; therefore, peening, cold flow, and frictional heat are lessened. The variable of blasting pressure was identified as the most significant; but angle, position, and distance of nozzle were also important. Time control was also an effective variable because of the increased erosion realized using harder medias. These variables were confined to workable ranges and successful processes were developed for wet blast deburring of this series of parts. The process was automated for production purposes.

Activity to automate the process was begun by modifying a small wet-blast cabinet. Three additional pressure lines were employed to establish four blast streams. A conveyor system was installed with interchangeable belts for use with several parts. The system was originally designed for manual feeding and automatic removal during continuous operation. Manual feeding operations were eliminated by the addition of an automatic stack feeder. Variable belt speed was used to control blast time. Nozzle positions were maintained by the use of fixed brackets with adjustments for blast distance and angle.

An area of concentrated effort throughout this project was the development of applicable deburring techniques for some other polycarbonate parts. After molding, holes are added to these parts as a secondary drilling operation which can be performed in two ways: gang drilling or point-to-point numerically controlled (NC) drilling. In the point-to-point NC drilling method, a single drill bit is used. The part is placed on a tape-controlled Pantex polar axis drill. All holes and counterbores are produced individually.

When the gang drilling method is used, a part is placed on a mandrel in a fixture which incorporates drill points for every hole and counterbore to be produced. With this approach, one cycle of the fixture drills all holes. The advantage of gang drilling over NC drilling is cycle time. It has been shown that gang drilling consumes roughly one third the time that NC drilling consumes.

These two types of operations produce different deburring problems. When the NC method is used, small burrs result at the edges of holes. These burrs are tightly attached but will respond to abrasive blasting operations. When hand deburring operations are performed to remove these burrs, magnification aides must be used.

When gang drilling methods are used, much larger burrs are produced. These burrs are accompanied by the smaller burrs seen in NC drilling, but are predominant. The larger burrs are the result of the reduced cutter speed that is inherent in gang drilling because of the drive system which uses separate universal couplings for each cutter to allow radial travel of each. The deburring time for parts drilled by this method is substantially increased and offsets the reduction in drilling time.

Initial efforts were aimed at establishing mechanical deburring methods that would be effective on both types of burrs, with emphasis on making gang drilled parts economically competitive. The effort was paralleled by efforts to improve machining techniques for both processes and eliminate burr problems at that stage of production. This included attempts to increase attainable speeds in gang drilling and using different cutter types and coolants in gang drilling and NC processes.

Burr problems are enhanced by the resilience of polycarbonate. All efforts have shown that polycarbonate burrs and flash are more subject to bending or peening than to abrading. Thus, the problem has many facets and can be summarized as the simultaneous removal of numerous flexible burrs with a minimum of manual effort.

Attempts to adapt abrasive blasting methods to the problem burrs began with the wet blast process. The following variables were studied:

- Pressure: 20 to 80 psi (138 to 218 kPa).
- Blast Angle: Perpendicular to 45°.
- Blast Time: 4 to 10 minutes, and
- Nozzle Distance: 1 to 3 inches (2.54 to 7.62 cm).

The most noticeable result from wet blasting was in part visual appearance. Signs of peeling, erosion, and staining were noted in samples runs. The peeling effects were thought to result from material molding conditions, especially moisture content. Parts from different molding lots of raw polycarbonate did not all show peeling effects. Erosion was noted on all parts but was most pronounced at high pressures (50 psi [345 kPa] and above) for long intervals. Staining was the result of media imbedding itself in material and leaching of media color.

Attention was then turned to dry blasting. Initial efforts using this process with glass beads and aluminum oxide were unsuccessful. Extensive peening and edge roll was evident, causing hole sizes to be under limit. It was decided that the burrs could possibly be removed by using a coarser blasting media than those previously used. Calculations indicated that the largest size of blasting media which could be used was mesh size 35. Attempting to use larger blasting media would result in the media being wedged in the hole.

Agrashell Grade AD7B (crushed walnut shell) was obtained for this experiment. The size of Agrashell AD7B is 35-60 mesh. The Agrashell blasting media was then sieved into two groups: mesh size 35-48 and mesh size 48-60. A finer size of Agrashell (mesh size 80-140) was also obtained for this experiment.

Four other process variables were considered during the test. The variables which affect the result of the dry blast operation are the distance between the part and the nozzle, the air supply pressure to the nozzle, the blasting time allowed, and the angle at which the blasting media strikes the part. A total of 30 combinations of the parameters shown in Table 1 was set up for the dry blast study.

Inspection results indicated that the burrs were not satisfactorily removed by any combination of the process conditions. Burrs were evident on all parts under seven-power magnification. The results indicated that the parts deburred using the coarser blasting media were more acceptable than the parts blasted using the finer blasting media (mesh size 80-140). The holes deburred using the fine blasting media would not accept a minimum diameter "GO" gage. The holes deburred using the two coarser blasting media contained burrs but the diameters were within the specified tolerances. The parameters at which the best results were obtained are shown in Table 2.

A study by Design Laboratory personnel yielded a dry blasting process which appeared to be more successful. Efforts were then initiated to compare this process with the one used during the previous in-house study. The comparisons are shown in Table 3.

Table 1. Parameters Used in Dry Blasting Study

Parameter	Limits
Blasting Media (Agrashell)	Mesh Size 35-48 Mesh Size 48-60 Mesh Size 80-140
Distance Between Part and Nozzle	3-4 in. (7.6-10.2 cm) 6-8 in. (15.2-20.3 cm)
Air Pressure Supplied to Nozzle	60 psi (414 kPa) 80 psi (552 kPa)
Blasting Time	120 s 240 s
Angle at Which Abrasive Strikes Part	45° 90°

Table 2. Dry Blast Parameters for Best Study Results

Parameter	Value
Blasting Media (Agrashell)	Mesh Size 35-48
Distance Between Part and Nozzle	3-4 in. (7.6-10.2 cm)
Air Pressure Supplied to Nozzle	80 psi (552 kPa)
Blasting Time	120 s
Angle at Which Abrasive Strikes Part	45°

Table 3. Comparison of Design Laboratory and Bendix Dry Blasting Processes

Item	Design Laboratory	Bendix
Equipment	SB-5 Econoblast, Inland, Indiana	Model CAB-3660, Empire
Nozzle Orifice	3/16 in. (0.40 cm)	7/16 in. (1.1 cm)
Air Jet Diameter	3/32 in. (0.24 cm)	5/32 in. (0.4 cm)
Air Delivery	48 ft ³ /min (22.7 dm ³ /s)	254 ft ³ /min (119.9 dm ³ /s) at 100 psi (689 kPa)
Media Capacity (sand/hour)	330 lb (149.7 kg)	1980 lb (898.1 kg)
Abrasive	Agrashell AD10.5	Agrashell AD10.5
Air Pressure	100 psi (689.5 kPa)	50-80 psi (344.7-551.6 kPa)
Blast Time per Side	6 s	60-240 s
Nozzle-to-Part Distance	7-3/4 in. (19.7 cm)	3-8 in. (7.62-20.32 cm)
Blast Angle	Perpendicular (Fixed)	45° (Moveable)
Support	Pedestal	Hand Held
Media Life	500 parts	Unspecified

Of these differences, the most meaningful were thought to be in those areas dealing with equipment differences such as nozzle and air jet sizes and capacity. The volume of media generated by the Bendix nozzle could cause a higher and faster heat buildup, which would be detrimental to abrasion. Efforts were initiated to duplicate the Design Laboratory process by acquiring a duplicate nozzle and holding fixture.

Other major factors are blast pressure, time, and angle. The process, reproduced in house, proved effective for removing small burrs such as those produced in NC drilling but had little effect on the larger burrs from gang drilling. The solution was to eliminate gang drilling processes, to

improve NC drilling methods by cutter design and coolant selection to minimize burrs produced, and to use the Design Laboratory parameters for removal of the remaining burrs. These process improvements have been incorporated and used extensively in production.

The use of abrasive blasting for deburring miniature plastic gears was also studied. Problems with both wet and dry blasting were similar and involved excess material removal and lack of physical control of the small parts in the blast stream. The machinery used will not develop blast streams below operating pressures of 20 psig (138 kPa). At this pressure, excess material removal and damage to fragile teeth were noted in both processes. In addition to these problems, sizable part-to-part variation was noted, which implies that fixturing would be required to control such variables as blast distance and angle. The general conclusion was that blasting with existing capability was not applicable to deburring miniature gears.

Tumble Deburring

The barrel tumbling method of deflashing and deburring has many similarities to the vibratory deburring process. The approaches are basically the same except that, with barrel tumbling, increased action inside the chamber and the flexibility to incorporate several types of carriers are obtained.

Equipment for this study consisted of a constant speed ball mill and various glass, ceramic, and metal containers of different volumes and diameters. The speed of rotation was varied by varying container diameter. The abrasive media used included finely ground flint, several sizes and shapes of silicon carbide, and fine aluminum oxide. Dry ice was used to cool various mixtures for several runs. Time ranges from 2 to 48 hours were used. This was determined to be a very significant variable, with 10 hours being minimum for the flat polycarbonate parts. A ratio of five parts per quart (946 cm³) of abrasive was used throughout this study.

The greatest success was attained with these parts using a combination of small and large media. Superior among these mixtures was aluminum oxide as the small abrasive combined with silicon carbide triangular-shaped large chips. The tumbling process was successful in edge deflashing of polycarbonate parts and was incorporated in the production process.

Aside from abrasive blasting, barrel tumbling was the most successful of the processes investigated during this project. With varying medias and times, this process showed versatility in material application. Both thermo-set and thermoplastic parts were successfully deburred. The material

spectrum included DAP, epoxy, polybutadiene, and filled and unfilled polycarbonate. Parts successfully deburred included small complicated moldings such as miniature gears.

These tests began using silicon carbide and steel grit abrasives in separate runs. Both materials were mesh 60 and the results with each were similar. In both cases, exposed surfaces were successfully deburred, but media tended to become wedged between gear teeth and other part features.

The next test series employed mesh 80 silicon carbide with similar results. Success was attained when silicon carbide powder was used as the abrasive media; however, tumble times of up to 48 hours were necessary for polycarbonate specimens. This time interval is not a major concern as no operator time is consumed and up to 200 parts can be run per cycle. Additional advantages are low equipment expense, simplicity, and repeatability.

Vibratory Deburring

The development of vibratory deburring techniques began with goals of establishing a more repeatable process that required few manual operations. Testing was performed using, again, flat polycarbonate parts. The following were identified as significant variables:

- Media--The type of abrading compound in which the parts were submerged;
- Frequency of Vibration--The number of vibrations per time interval of the container;
- Amplitude of Vibration--The limits of motion of the container for each vibration;
- Volume--The ratio of parts to media in the container during vibration;
- Time--The length of time that parts and media are allowed to vibrate; and
- Temperature--The heat generated by vibration, or any induced control of vibratory climate.

The media evaluated were chosen from several sources for differences in size, shape, and hardness. Several runs were made using different media and mixtures of media. Temperatures used were uncontrolled room temperature or -240°F (-151°C) for the various runs. Ratios of 25 parts to 7 quarts (6625 cm³) of media were used, removing the parts at predetermined intervals for time evaluation. No effect could be seen around holes

in these parts. This is due to the type of flow of media over part surfaces generated by vibrating. Such motion applies no force to the abrasive; therefore, no cutting action was seen on features with difficult access.

General conclusions were that vibratory deburring was effective on surface and edge flash, but that little effect could be expected on internal features. No significance could be attached to temperature in this study.

Explosive Deburring

Explosive deburring, also referred to as "thermal shock deburring," is a method of using heat and shock waves from controlled explosions for removal of burrs. It was developed mainly for use on metal parts. The part is sealed in a pressure vessel which is then pumped to a desired pressure with a flammable gas and oxygen mixture. This system is then ignited. The heat generated has a melting effect on the part which is more pronounced in thin cross-sections (such as flash and burrs). The amount of heat generated varies with the pressure in the vessel; therefore, a level is found that removes flash without sizable destruction to the part. The shock waves generated aid in the removal of melted material.

Development work on explosive deburring was performed by Materials Engineering. Hydrogen and oxygen were used for the explosive gas mixture. Spark plug ignition was employed. Parts of several materials were tested, including polyethylene, polycarbonate, polypropylene, and acetal.

Evaluation of parts deburred by explosive deburring was not encouraging. The edges of the parts were distorted and some melting was evident. Discoloration of surfaces indicated degradation of material had occurred. In addition, deburring was not sufficient, as several large burrs were evident inside holes. Surface peeling or increased surface roughening was also evident on most samples. It was shown that degradation could be avoided by low-pressure hydrogen-rich mixtures, but burr and flash removal was still unsatisfactory. General conclusions were that, as it exists, this process is not applicable for deburring and deflashing thermoplastic materials to current quality levels.

Flame Deburring

The process of flame deburring is similar to explosive deburring in that it uses instantaneous heat to melt burrs and flash. To test this method, a fixture was devised that incorporates an acetylene torch held in place by a standard lab stand and clamp device (Figure 3). The torch is positioned in a pipe "T" which is bolted to a cylindrical collar forming the throat or heat

Figure 3. Flame Deburring Fixture

chamber of the fixture. Above this chamber is a cone-shaped, rolled wire mesh screen which forms a drop chute. Control of the height of this chute allows some variation in the speed of the part as it enters the throat. The intensity of the flame is varied through the use of the control valve on the torch.

The initial efforts were conducted to evaluate three variables: flame intensity, speed of entry, and material. With this setup, the range of entry speed was not great enough to show any response. The medium flame intensity was determined to be the most usable of the three intensities tried. Parts were not noticeably melted at this flame level and some burr response was noticed on polyethylene parts.

The next step taken was to use polyethylene and repeat exposures until deflashing was accomplished. Six series were run using soft, medium, and hard flames. The flame intensity was determined by valve setting only. No further evaluation of heat was attempted in this phase. Series 1 and 2 consisted of making one exposure and two exposures, respectively, to a soft flame. Series 3 and 4 were the same except a medium flame was used. Series 5 and 6 in turn used a high flame intensity.

Again, the best results were obtained using the medium intensity flame. Melting occurred when using a high intensity flame to the extent that parts were visually distorted. The effects of the soft flame were insufficient in flash removal. Parts exposed to medium intensity flame were successfully deflashed, but some rounding of corners was evident. This indicates flash was not removed but withdrew to the part surface when melted.

Attempts to establish this process for other materials were unsuccessful, mainly due to insufficient heat. Parts used in these efforts included a polycarbonate miniature gear configuration, several small moldings of acetal resin, and one diallyl phthalate switch. It was realized that, in addition to more heat, control of flame intensity would be necessary to further this development.

An additional problem with this type of deburring is the safety aspect. Use of an open flame for industrial purposes presents a fire hazard. Such an operation would require installation of extensive fire preventive apparatus.

Letters were sent to several vendors involved in the manufacture of flame control equipment. A unit was ordered through Materials Engineering; however, no additional work was to be performed without adequate fire prevention equipment. Additional study was made to establish firm expectation for

future use of this process before making large expenditures for equipment. It was determined, from previous observation and projections of future product types, that the applications for this process would be limited.

Cryogenic Deburring

The use of low temperature during deburring operations was theorized to be an aid in the use of other deburring methods for thermoplastic materials. The reduced temperature would serve to stiffen burrs and flash and make them brittle, allowing easier fracture during tumbling, vibrating, or abrasive blasting.

During testing of vibratory deburring, several runs were conducted using liquid nitrogen and temperatures of -240°F (-151°C). These tests were generally unsuccessful with or without low temperature control; no improvement could be determined from the use of low temperature.

In barrel tumbling endeavors, dry ice was added to containers in several experiments to lower temperature. These temperatures were not monitored, but estimates of effective temperature are in the range of -90 to -100°F (-68 to -73°C). Again, the effects of low temperature alone were negligible.

These failures could be attributed either to insufficient heat soak of materials that inherently exhibit poor heat transfer properties or to offsetting frictional heat that occurs during abrasion, making part temperatures less extreme. This offsetting heat was observed when attempts were made to establish cryogenic enhancement in dry blasting. During this study, polycarbonate samples were exposed to liquid nitrogen for two hours. Parts were immediately blasted upon removal. It was observed that surface heat buildup from blasting occurred so rapidly that little additional effect was realized in burr removal. The problem then, with the use of cryogenics, appears to be maintenance of low temperature throughout the deburring operation.

Slurry Deburring

Slurry deburring methods are characterized by the flow of abrasive media, in a low viscosity liquid carrier, through or across a surface to be deburred while pressure is maintained on the fluid. This, in theory, will maintain a direct continuous abrasion on the entire surface and erode the areas of least stability, which would be burrs and flash. In addition to the erosion effect, it was felt that cycling the abrasive fluid in opposing directions would produce a fatiguing effect on large burrs. This could be accomplished by periodic pulsation or shuttling of the direction of fluid flow.

To determine the pressure or force range which would be necessary to deflect burrs, a special probe attached to a force gage was used. Measurements were made on 115 holes from several sample parts and an average deflective force of 4 oz. (1.1 N) was determined. This equates to about 80 psi (551.6 kPa) minimum surface pressure for the drilled polycarbonate parts.

An experimental machine was fabricated that incorporates two pieces of 9-inch (22.9 cm) pipe with welded flanges, a holding mandrel mounted centrally between the two, a rubber diaphragm closing one end, and an electrically driven cam plate to control diaphragm deflection (Figure 4). Operation of the machine consisted of filling the lower chamber with a liquid and abrasive mixture and installing the part. When the motor is started, the cranking action forces fluid up through the part on the forward stroke. On the return stroke, fluid is drawn back through the part by the vacuum created.

The maximum operating speed of this fixture was 24 cycles per minute. The amount of slurry forced through the part could be varied by changing the cam wheel and washer diameters. Water with no abrasive added was used for initial tests to investigate the fatigue approach. After three hours of continuous operation, no change could be noted in the location or size of the burrs. Addition of mesh 400 aluminum oxide abrasive for the next series of operations was intended to add abrasion to agitation inside the chamber. Again, cycles up to 3 hours yielded no effect on burrs. This was due to the lack of effective suspension of abrasive media in the water as shown by the precipitation and caking of media in the lower chamber.

By using oil as a carrier, the viscosity of the deburring fluid was increased. A higher viscosity carrier should be more capable of holding abrasive media in suspension, thus enhancing abrasion. Again, the precipitating tendencies of the media were predominant. Changing the media to silicon dioxide did little to establish media suspension. The addition of a pressure gage to the apparatus showed that effective internal pressure was not exceeding 3 psig (20.6 kPa), which was far below the estimated required pressure. It was therefore concluded that the rubber diaphragm method for establishing flow in slurry deburring was not satisfactory, and design was initiated for a second phase of slurry deburring equipment.

The new machine was to be capable of maintaining media carrier agitation while establishing pressures in the 80 to 100 psi (552 to 689 kPa) range. To accomplish this, a ten-gallon (38 dm³) paint spraying pressure tank, rated at 110 psig (758 kPa), was obtained (Figure 5). The can was equipped with an air motor to drive a rotary mechanical agitator inside the tank, thus eliminating media precipitation problems. The chamber from the first generation machine was converted by removing the rubber diaphragm and

Figure 4. Diaphragm-Type Slurry Deburring Fixture

Figure 5. Unidirectional Slurry Deburring Fixture

replacing it with a steel plate through which a pipe nipple was welded. The other end of the chamber was open. A pipe nipple was also inserted in the bottom of the paint tank. Plumbing between the chamber and tank included a ball valve for control of flow from the tank. The bottom, or open end, of the chamber dumped into a large catch box. To start the sequence of operation, with the ball valve closed the tank was filled with abrasive slurry and the top was lowered into place and secured. The agitator was then started and allowed to run for several minutes to ensure media suspension. Tank pressure was attained by attaching a 100 psi (689 kPa) air line to the nozzle in the lid. Opening the ball valve allowed slurry to be forced into the upper section of the deburring chamber. When this section was filled, pressure from the air line forced the slurry through the holes in the part.

Several types of abrasive were used in the initial evaluation. It was determined that mesh 400 silicon dioxide worked best, as other medias of larger sizes showed tendencies to collect in upper portion of chamber and block media flow through part holes. The first runs consisted of two shots from each side of the part. A shot consists of approximately 8 gallons (30 dm³) of abrasive slurry. The ratio of media to carrier was increased for subsequent runs, with limits established by the amount of media the air-motor-driven agitator could move. Sixteen shots were made at the high level, which consisted of 75 pounds (34 kg) of abrasive to 8 gallons of carrier. Flow through the chamber was reversed after every two shots. This was accomplished by disassembling the part chamber, flipping the part and mandrel, and reassembling. With this method, extensive time was consumed in reloading the pressure tank after each shot and disassembling and reassembling the chamber for flow reversal. Also, the number of shots required contributes heavily to time consumption; the total amount of flow represents about 130 gallons (0.492 m³) of liquid. Another problem was the catch box system employed for fluid recovery. The system allowed splashing and loss of fluid; collecting of media in the bottom of the box, which had to be scooped out for reloading the tank; and generally untidy working conditions.

This approach, however, was proven valid as parts completing the maximum-concentration, 16-cycle process were successfully deburred. The effectiveness of this process is dependent on the pressure on the deburring fluid, the volume of flow, and the concentration of abrasive media. The high concentration of media used had an additional effect, which was higher slurry viscosity. This effect was noticed and investigated, and led to the putty extrusion deburring process discussed later.

The next effort in slurry deburring was to conceive ways of reducing the process time required. The third-generation deburring fixture incorporated two paint tanks of the type used in the previous method (Figure 6). A mandrel

Figure 6. Bi-Directional Slurry Deburring Fixture

mounted between the two tanks served as a holding fixture for the part. Both tanks were equipped with agitators, and the entire fixture was mounted in a frame to allow rotation so that either tank could be positioned above the part. Either tank could be pressurized. This fixture provided continuous cycling, eliminating both the need to perform disassembly for flow reversal and the need to reload for each shot (Figure 7).

To start the operating sequence, the slurry is added to the bottom vessel, the agitator is started, and the mandrel and upper tank are placed and secured. The unit is then rotated 180° by an electric motor to position the filled tank above the part. This increases agitation, shifts any precipitate to a more functional position above the part, and places air pressure on the upper surface of the fluid. The air hose is then coupled, pressurizing the upper tank and initiating flow, and the agitator on the bottom tank is started to maintain agitation. The bottom tank vent remains open to relieve air pressure in the lower tank. When the slurry has emptied into the bottom tank, the air source in the top tank is disconnected, the lower air vent is closed, and the upper vent is opened. The fixture can now be again rotated 180° and the next shot initiated with flow in the opposite direction, beginning another cycle.

Problems encountered with the function of this unit included venting and leakage. The major problem was establishing the desired pressure on the slurry. Monitoring the pressure revealed that only 55 to 60 psig (379 to 414 kPa) was being reached in the tank because of the speed of flow of the slurry. To increase the effective pressure, an auxiliary tank was added to the system, capable of establishing 120 psig (827 kPa); however, this did little to increase slurry pressure. The next approach to increasing effective pressure was to increase fluid flow resistance by increasing carrier viscosity. This was accomplished by substituting oil for the water carrier previously used.

With the desired pressure attained on the slurry, testing began by running parts in 10-cycle increments. It was observed that large machining burrs were removed within the first 10 cycles. After 50 cycles the effect on small burrs and flash was not sufficient to yield acceptable products.

Putty Extrusion Deburring

The viscosity/pressure relationships, displayed in both single- and dual-direction slurry deburring fixtures, led to the conception of putty extrusion deburring. In this approach, abrasive media is mixed with a putty-like substance. This mixture is then extruded, under pressure, through the holes in a part. The effect sought from this approach was increased direct pressure on the part to obtain increased abrasion and yielding of burrs and flash.

Figure 7. Cyclical Operation of the Bi-Directional Slurry Deburring Fixture

A simulated transfer mold was built to be used in a 100-ton (890 kN) transfer press for initial testing of this process (Figure 8). The mold parting line served as access for part insertion and removal. Deburring putty was placed in the transfer cylinder, and transfer pressure was used to perform extrusion. Extruded material was collected in an open chamber beneath the part.

Cycles were run with varying ratios of putty and media. Tear-down time for flow reversal was time consuming. Extensive cleanup was also necessary on each part before visual evaluation of burrs was possible. In some cases, the putty had to be punched with toothpicks from the holes. This was more time consuming than hand deburring and was detrimental to hole dimensions. The general appearance of the part was also worsened.

It was concluded that the deburring effects of the putty extrusion process showed no improvement over those of the slurry method.

ACCOMPLISHMENTS

Tumble deburring processes are in use on several small molded parts of both thermosetting and thermoplastic materials. The variables having been identified and the expected effect of each determined, this process now exhibits increased versatility and will lend itself to extended use where external surface and edge deburring is required. Vibratory deburring shows a lesser deburring and deflashing effect, but will find its uses where part fragility is a problem. In using this process, it should be realized that increased effects can be realized by varying the abrasive media and deburring time.

Explosive deburring, with the degree of control that is currently available, is not applicable to plastic moldings. This is especially true of thermoplastics. Flame deburring applications may be found for soft thermoplastic materials such as polyethylene when tolerance levels and quality standards are not too demanding. This process will not be applicable to the majority of current or projected products.

Cryogenic deburring enhancement could possibly be of use if successful techniques are established for maintaining the low temperature. As currently used, these techniques afford minimal improvement when used with stiffer thermoplastic compounds such as acetal. Production processes for such parts have shown little improvement from the use of this control.

Abrasive blasting techniques have, by far, been the highlight of this development activity. Special applications for thermoset and thermoplastic materials have shown immediate effects.

Figure 8. Putty Extrusion Deburring Fixture

Both wet and dry blasting techniques have shown this production readiness and their applications are expected to show additional time reductions to those already experienced. In combination with improved drilling techniques, abrasive blasting has provided substantial reductions in deburring time. With controlled abrasion levels, applications to thermosetting materials, with or without metallic inserts, are extensive. In addition to the reduction of deburring time, the surface finish established when blasting these thermoset parts is advantageous, as the majority of assembly applications require either potting or bonding. The needs for additional cleaning and surface preparation operations are eliminated. Reductions in both standard hours and lead times have been noted.

Identification of process parameters in abrasive blasting has shown that the process has a sensitivity previously unexploited in blasting techniques. The

comparison of high abrading levels in wet blasting with heat evolution in dry blasting provides a wide range of material processability in conjunction with pressure, time, distance, and orientation controls. The availability of abrasive medias exhibiting different characteristics further enhances this versatility.

Additional refinements in such areas as automation, media/carrier ratios, and blast angles will need to be established for each part to be exposed to deburring processes as part of the development of each part. It is hoped that the results of this development effort will stimulate awareness of mechanical deburring techniques among process engineers; these techniques warrant consideration for many future applications.

FUTURE WORK

No more general development work on mechanical deburring of plastics is presently contemplated. Any future work will be limited to specific applications.