

[54] THERMAL TREATING CONTROL

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[22] Filed: Jan. 10, 1969
[21] Appl. No.: 790,366

[52] U.S. CL.....148/128, 73/362, 328/3, 328/127, 328/145
[51] Int. Cl.....C21d 1/00, G06g 7/24
[58] Field of Search.....73/362; 328/3, 127, 145; 148/1, 128

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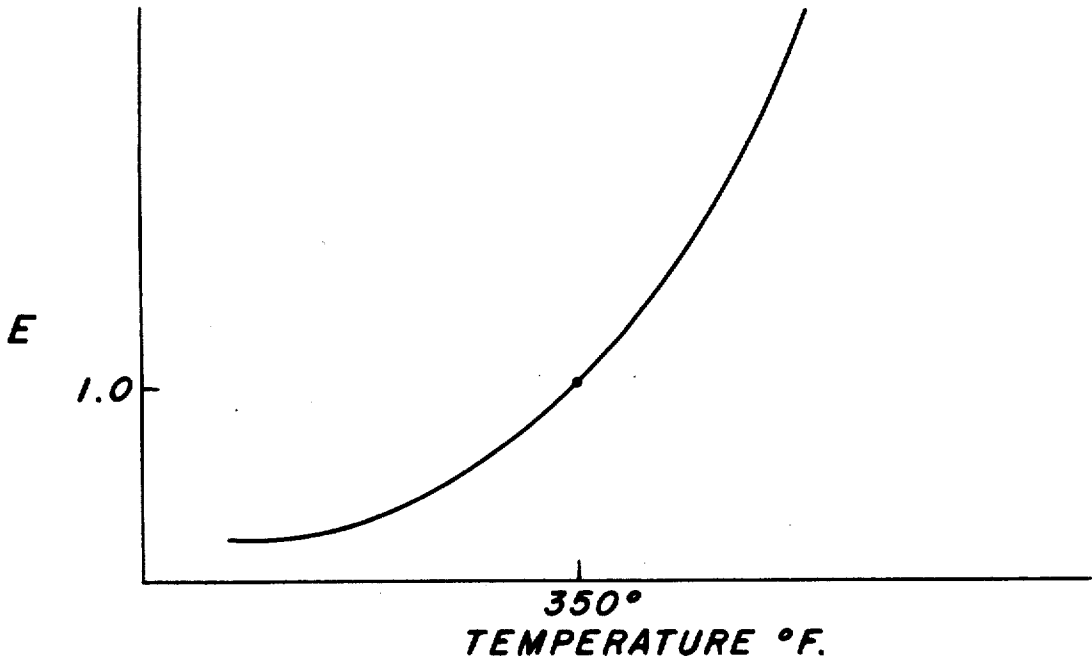
Metals Handbook, 8th Ed. Vol. 2, pages 271- 281.

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[57] ABSTRACT

A method for imparting to a metal or other body the predetermined effects of a specific thermal exposure at a preselected temperature T', but where the actual temperature of the body varies during the treatment from the desired temperature T', is provided by maintaining the treatment until the cumulative thermal effects reach a predetermined value. Also contemplated is an arrangement for measuring cumulative time and temperature effects during a thermal treatment wherein means are employed to provide a signal output which represents the thermal effect function based on the temperature which signal is fed to a means accumulating that signal and providing an additional signal upon reaching a predetermined accumulation.

8 Claims, 3 Drawing Figures



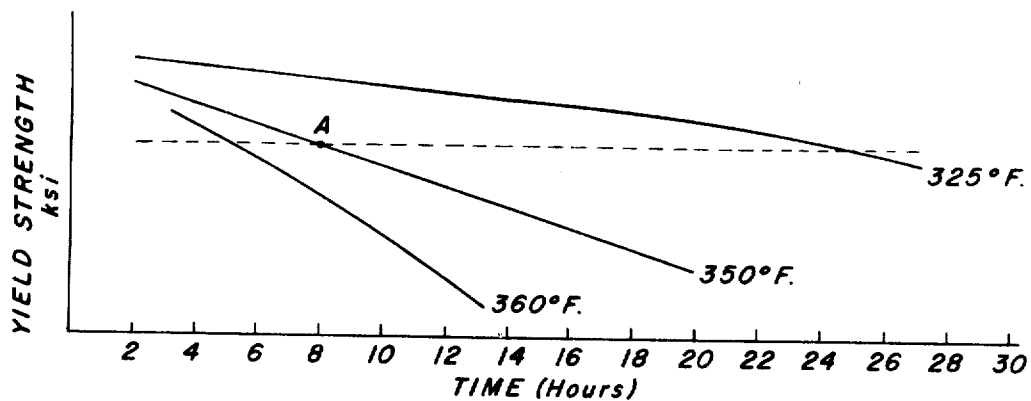


FIG. 1.

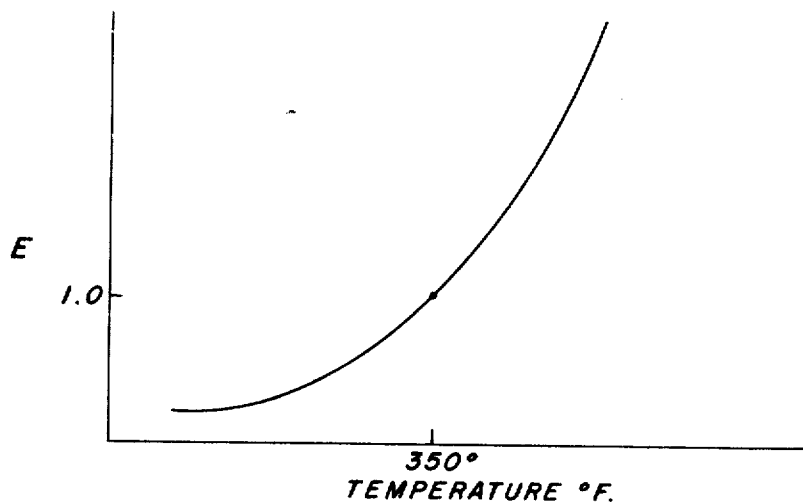


FIG. 2.

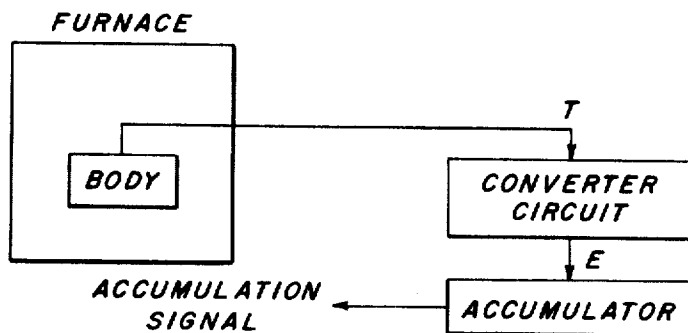


FIG. 3.

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THERMAL TREATING CONTROL

BACKGROUND OF THE INVENTION

There are various industrial applications where a body of material is thermally treated to achieve certain desired characteristics. One example is the thermal treatment of metal. In many applications, the thermal treatment is accomplished by subjecting the body to a preselected temperature for a duration of time predetermined to achieve the desired result which is often the development of a particular property such as strength or resistance to deterioration in service. In several industrial applications, variances in the temperature of the body may not be particularly critical since the materials involved may be relatively insensitive and undergo changes slowly during thermal treatment so that the body may remain at an elevated temperature for a considerable time after the desired results have been reached in the thermal treatment. For instance, in artificially aging some aluminum base alloys, an alloy body may be heated to a temperature of about 275° F. for a period of time which can vary between 10 and 40 hours. The material will exhibit about the same properties whether removed after 10 hours or after 20, 30 or more hours since, for the most part, the alloy body undergoing such thermal treatment is relatively insensitive to the passage of time and minor variations in temperature. However, there are also many cases where the material is quite sensitive to both time and temperature variations and the properties of the material may vary markedly with seemingly minor changes in either temperature or exposure time. In some cases, a property peaks at a maximum level and then diminishes with continuing thermal exposure. Also, it is sometimes necessary to continue the thermal treatment of an alloy beyond the peak in a first property, for example, strength, in order to sufficiently develop a second property, for example, resistance to stress corrosion cracking. In such a case, there often exists a specific optimum time at temperature to achieve the desired development of the second property while minimizing the decrease in the first property. An example is the artificially aging aluminum alloys of the zinc-magnesium-copper type in order to achieve a high strength level together with immunity to stress corrosion cracking. Such an aging treatment is described in U.S. Pat. No. 3,198,676, namely, a two-step aging cycle for aluminum alloys containing 4.5 to 14 percent zinc, 1.5 to 3.8 percent magnesium, 0.75 to 2.5 percent copper and one or more of several disclosed hardeners. The two-step artificial aging cycle contemplates a first thermal exposure wherein the alloy body is heated to 175° to 275° F. for 3 to 30 hours. This is followed by a second step wherein the alloy body is heated to a higher temperature of about 315° to 380° F. for a period of time of up to 100 hours but not less than a value dependent on the section thickness and composition of the member. This thermal treatment imparts high resistance to stress corrosion cracking with some loss in mechanical strength which passes through a peak level and then diminishes during the second aging step, the strength property of the alloy being somewhat sensitive to aging time at temperatures above 300° F. There are many applications, for example, in the aircraft industry, where it is desired to achieve high resistance to stress corrosion cracking while retaining in the alloy body the highest possible level of strength and with a high level of consistency. In such applications, the optimum aging time and temperature to achieve these results can be determined by trial under carefully controlled conditions. However, in the normal operation of an industrial furnace, a serious problem arises in that the furnace temperatures tend to vary during the aging treatment. Another complication arises because of the fact that an extensive heat-up period is usually necessary to bring the alloy body to the hold temperature. Heat-up times of several hours are not uncommon. Considerable thermal treating effects can occur during these heat-up periods. Both heat-up rate and the extent of temperature variation from the desired or target temperature may differ considerably from one furnace load to the next. This renders it extremely difficult to reproduce the

results which might typically be based on employing a constant aging temperature of 350° for at time of 8 hours. It is noteworthy that, in the particular aluminum alloy thermal treatment described above, about three to four times as much aging time is required at 325° F. as at 350° F. to obtain the same results. Approximately twice as long a time is required at 335° F. as at 350° F. In a large industrial furnace it can take an hour or more to go from 335° F. to 345° F. A considerable variation in aging effects occurs even within a furnace temperature tolerance of plus or minus 10° from the 350° F. target temperature. A variation of as little as 5° alters the aging effects substantially. For instance, 8 hours of aging at 345° F. is the equivalent of about 6½ hours at 350° F., and 8 hours at 355° F. has the same effect as 10 hours at 350° F. Where precise control of thermal treatment effects is desired, such unavoidable variations in temperature can result in high rejection rates. Similar problems arise in thermal treatments of various other materials which undergo property changes rapidly during thermal treatment.

STATEMENT OF THE INVENTION

In accordance with the invention, a body may be thermally treated to have imparted thereto, with improved precision and accuracy, the predetermined effects on certain properties of a thermal exposure at a preselected temperature T' wherein the actual temperature T of the body varies from the preselected temperature T' by continuing and maintaining the thermal treatment until the value of K in the following relation reaches a value predetermined with respect to the certain properties:

$$E_1t_1 + E_2t_2 + E_3t_3 + \dots + E_nt_n = K$$

where t is the period of time at body temperature T and

E is the correction factor for temperature T in terms of equivalent thermal effect, which may be equivalent time, at temperature T' which factor is predetermined with respect to the particular properties sought to be developed during the thermal treatment.

Where it is ascertained that the desired thermal effects are those derived from an exposure at the preselected temperature T' for a period of time ranging from t' to t'' , E may represent equivalent time at T' for the various temperatures encountered and K then ranges from t' to t'' .

Where the E function is continuously monitored, which is quite convenient in actual practice, the above summation may be expressed:

$$\int_{E_1}^{E_n} \int_{t_1}^{t_n} dEdt = K$$

The invention additionally contemplates a process wherein the body is first heated to a temperature at which the certain properties of interest begin to respond to the thermal treatment. It is then further heated to increase its temperature toward temperature T' . If, as intended, the temperature reaches T' , it is held there. As is often the case, the temperature will fall within a band bracketing temperature T' , for instance, within a 10° F. band bracketing temperature T' (i.e., $T' \pm 5^\circ$ F.). At least during the period of the treatment where the temperature of the body is within the range where the properties of interest respond to the treatment, there is continuously provided a signal output which represents the E function described above. This signal output is accumulated until a predetermined accumulation is reached.

The invention further contemplates an arrangement for measuring and accumulating time-temperature thermal effects during a thermal treatment of a body whose temperature varies from a preselected or target temperature T' during the treatment. The arrangement includes means to provide the first signal output which represents the E function described above. Sometimes the means may include means to provide a first signal output which represents the temperature of the body and a second means associated therewith to provide the

signal output representing the E function. Additionally, means are required for accumulating the E signal output to provide an additional signal upon reaching a predetermined accumulation.

In the ensuing description, reference is made to the drawings in which:

FIGS. 1 and 2 are graphical plots of the type typically useful in practicing the invention, and

FIG. 3 is a block diagram illustrating an embodiment of the invention.

The invention is described for convenience and ease of understanding with reference to the thermal exposure employed in artificially aging certain aluminum base alloys to obtain high strength together with high resistance to stress corrosion cracking as was mentioned in the introductory portion of this description. The particular member being thermally treated might be a forging of considerable size, say 500-700 pounds, and having a rather nonuniform cross section varying from about 1 to 5 inches in thickness. The illustrative forging under consideration is composed of an aluminum base alloy containing, nominally, 5.6 percent zinc, 2.5 percent magnesium, 1.6 percent copper, 0.3 percent chromium, the balance being aluminum and incidental elements and impurities. This alloy carries the Aluminum Association designation 7075 and is often employed in the aircraft industry. As mentioned earlier, a special thermal treatment is employed to impart the high resistance to stress corrosion cracking property. This treatment includes a two-step aging cycle wherein the member is first desirably held at a temperature of about 225° F. for about 3 to 30 hours and is then desirably held at a temperature of about 350° F. for a time of about 5 to 8 hours as determined under controlled conditions. At a relatively early stage of the second aging step, the strength of the body starts to diminish, the higher the temperature, the more rapid the decrease in strength with passing time. In order to minimize the strength decrease which occurs so rapidly in the second, higher temperature, stage of the treatment, an optimum thermal effect accumulation which may be optimum time at a preselected temperature T' can be determined by trial, preferably under carefully controlled conditions.

Since the temperature experienced by the body during a thermal treatment, especially in an industrial furnace, will vary somewhat from the preselected or target temperature, the comparative effects of temperatures other than the preselected temperature T' are also determined in terms of equivalent thermal effect at the preselected temperature. A suitable base for this comparison is the equivalent time at T' for the various temperatures. This equivalence is best determined with respect to one or more of the particular properties of interest in the treatment especially the more sensitive property or properties. In the specific case under consideration, the sensitive aspect is the tensile properties, which vary markedly with thermal conditions. In the determination, several test specimens are given thermal exposures at different temperatures and for varying times and the resulting strength measured. Because of the small size of the specimens and carefully controlled conditions, heat-up time effects can be reduced to a negligible level so that the time at temperature condition is achieved in a highly accurate manner. The determinations can be repeated to further assure accuracy. From the data developed in the tensile tests, a plot is made of yield strength versus time for each temperature which results in a family of curves as shown in FIG. 1. Referring to that figure, it is observed that the strength steadily decreases with longer treatments. Peak strength is achieved relatively early in the treatment and somewhat before immunity to stress corrosion cracking is reached. Thus, only the strength decrease or "downhill" characteristic is plotted in the illustration used in this description.

From FIG. 1 it is apparent that the effect of a particular temperature with respect to strength is readily determined in terms of the equivalent effect at 350° F. or any other target temperature. By drawing a horizontal line, for example,

through point A of the 350° F. line, the time to achieve the same effects at various temperatures is readily observed. A correction or equivalency factor (E) can be determined by the ratio of time t at temperature T divided by the equivalent time at T' (350° in the illustrative embodiment). Accordingly,

$$E = \frac{t_r}{t_{r'}}$$

where t_r is the time at a particular temperature T, and $t_{r'}$ is the time at the preselected temperature T' required to achieve the same strength.

The correction or equivalence factor E is obviously unity when $T=T'$. FIG. 2 is a plot of the equivalence factor E versus temperature determined in accordance with the foregoing. It can be seen that in the illustrative case the E factor does not vary linearly with temperature in that temperatures significantly lower than 350° would require extensive time periods because of very low E values and temperatures significantly over 350° involve very short time periods, as is also reflected in FIG. 1.

From the foregoing illustration, a guide is set forth for predetermining the equivalence factor E for any thermal treatment on a metal or other material. Once this is determined for a particular metal alloy or other material, it can be utilized in any thermal treatment of any body thereof, irrespective of its shape or size. Hence, it is often advisable to exercise care in this determination.

In the case of the particular aluminum alloy thermal treatment used for illustrative purposes in this description, an empirical relationship has been determined for E whence:

$$E = e^x$$

where

$$x \text{ equals } \frac{A}{T} - \frac{A}{T'}$$

$$A \text{ equals } 27,942, \text{ and}$$

e is the base of the natural logarithm.

This relationship holds for most aluminum base alloys where the thermal treatment varies from about 200° to 450° F. However, it is preferable to predetermine the E function for each alloy and thermal treatment as it varies with respect to temperature for each individual alloy and each particular property where the highest degree of precision and reproducibility are desired.

The optimum thermal effect accumulation, or the value of K in the equation, unlike the E vs. temperature relation, can vary quite significantly with the size and shape of the particular body being thermally treated. To determine the optimum thermal effect accumulation, which may be measured in terms of time to provide an optimum time, and referring again to the illustration regarding aluminum alloy forgings, sections are removed from the forging and held at the preselected temperature T' of 350° F. for different lengths of time. The forging, previous to removing the sections, had been solution heat-treated, quenched and subjected to the first, or low temperature, aging step to place it in the proper condition for evaluating the thermal effects during the second higher temperature step. Tensile test specimens are removed from the sections and the yield strength measured to provide exposure time vs. strength data. In addition, electrical conductivity measurements are made on each section to provide an indication of the extent of precipitation and the extent of the resistance to stress corrosion cracking. For the particular alloy under consideration, an electrical conductivity of 38 percent of the International Annealed Copper Standard, IACS, or higher, is considered a measure of sufficiently high resistance to stress corrosion cracking. From the data thus obtained, a pattern is revealed whereby with increasing time exposures, strength steadily decreases and conductivity increases quickly at first and later flattening out. The optimum time range is that where the electrical conductivity reaches 38 percent IACS and where the strength is not diminished excessively.

While the foregoing determination of optimum thermal effect accumulation was discussed with reference to time, this determination can be performed in the practice of the invention in terms of the cumulative effects themselves, that is, instead of recording the time and temperature that each forging section spends in the furnace, the above-mentioned E signal accumulation can be employed. This would compensate for even the relatively small error which might be introduced because of temperature fluctuations or inaccuracies in measuring time or temperature. The accumulation which corresponds to the best properties is used as the predetermined accumulation value in practicing the invention. This value, as indicated earlier, would correspond to the optimum or ideal time range, t' to t'' .

The invention also contemplates an arrangement for measuring cumulative time-temperature effects in a thermal treatment. The arrangement contemplates means to provide a signal output which represents the E function together with means for accumulating this output to provide an additional signal upon reaching a predetermined accumulation. This arrangement is illustrated in FIG. 3 which shows a body being thermally treated in a furnace. A temperature-sensing device provides a signal to a conversion means which provides the E signal to the accumulating means. Where the E function is an electrical output, the accumulating means may be a capacitor. The capacitor upon reaching saturation discharges and each discharge can be recorded or counted by a suitable counting means. The accumulating means may be supplemented by a control means whereby the thermal treatment is automatically interrupted upon reaching the predetermined accumulation. Alternatively, a visual or audible alarm can be provided at this stage. In practicing the invention employing such an arrangement, a range of the number of capacitor discharge counts corresponding to the optimum thermal effects can be determined. This, as indicated above, corresponds to the ideal time range, t' to t'' , at the preselected temperature T' although this time range might not be specifically determined. If desired, the time range can be determined by observing the hold time required to achieve optimum results. The thermal effects resulting from heat-up effects and temperature variation can introduce some error in determining optimum time as such but are automatically compensated for by simply determining the optimum signal accumulation value. This may be determined for a particular body of material for the specific properties of concern in terms of capacitor counts or other accumulation measure and without regard for actually determining the ideal time range (t' to t'').

When thermally treating a body in an industrial furnace, the body is treated until the predetermined accumulation or number of capacitor discharge counts is reached. At this point, the member is removed from the furnace and will be found to exhibit levels in the properties of interest very close to the optimum levels achieved in the laboratory.

The E signal output can be provided by various suitable means of correcting or altering a base signal such as temperature. For instance, where E varies with temperature in a logarithmic fashion, the function can be provided by first providing a signal output representing the temperature of the member being treated. A thermocouple or an electric resistance thermometer serves the purpose although there are other known means for achieving the same effect. This temperature signal can be fed to an antilog conversion circuit to provide an output signal which represents the antilogarithm of the temperature. This output, representing the E function, can then be fed to the capacitor accumulation means.

Other means for performing the same function might include a thermocouple whose output is fed to a rheostat having an output which corresponds to the E versus T relationship. Where the relationship is logarithmic, the rheostat would have a logarithmic output. This output can be fed to a variable speed motor which drives a counter. When the desired number of counts is achieved, an alarm or other suitable signal is provided. Another arrangement might include a logarithmic

gear on the shaft of a linear rheostat where the logarithmic gear is driven by a conventional gear positioned in accordance with the temperature. The variable speed motor and counter just described could also be employed in this device. If the E versus T function is something other than logarithmic, this function obviously can be incorporated into any of the means just described by the use of known conversion techniques which need not be elaborated upon in this description. Various means including mechanical, electrical or combinations thereof, may be employed in these thermal treatment measuring and accumulating arrangements. For instance, antilog or digital computers can be utilized to convert a thermocouple or other temperature signal into the corrected signal, the E function, accumulate this output and provide a signal when a preset accumulation is obtained.

A better understanding of the invention evolves from the following illustrative examples.

A forging approximately 4 inches thick and composed of aluminum base alloy containing nominally, 5.6 percent zinc, 2.5 percent magnesium, 1.6 percent copper and 0.3 percent chromium, balance aluminum and incidental elements and impurities is solution heat treated and further thermally treated in accordance with the two-step aging treatment described in U.S. Pat. No. 3,198,676. In the first step, the member is heated to a temperature of 250° F. for a period of about 10 hours. In the second step where the resistance to stress corrosion cracking is developed but where strength rapidly decreases because of the higher temperature, it is necessary to employ the improvement described herein so as to retain the highest possible strength consistent with achieving high resistance to stress corrosion. This is accomplished by obtaining information of the type described above with respect to FIGS. 1 and 2. The FIG. 2 plot is found to be essentially logarithmic over the temperature range under consideration. Using 350° as the preselected temperature T' , the optimum thermal effect accumulation or optimum duration is determined by exposing several forgings to treatment at a temperature of 350° F. for varying lengths of time and then determining the resulting strength and electrical conductivity. In these determinations, an arrangement of the general type described earlier is employed. This arrangement includes a thermocouple which is attached to the forging during the treatment. Also included is an antilog converter which converts the temperature signal to an antilogarithmic function. Because of the low output inherent in thermocouples, an amplifier is disposed in the circuit between the thermocouple and antilog converter in order to provide an input more suitable to the converter. The converter output is connected to a capacitor and a counter is arranged to count each capacitor discharge pulse. Employing this particular arrangement in the laboratory where the optimum aging conditions are determined, the results indicate that optimum strength and resistance to stress corrosion qualities are achieved when the capacitor count indicator reaches a certain number of counts corresponding to about 6 hours at 350° F. The optimum tensile and yield strengths are, respectively, 70,000 and 60,000 p.s.i. and the electrical conductivity exceeds 38 percent IACS which indicates adequate resistance to stress corrosion.

Forgings aged in a conventional furnace with conventional controls vary from this high level down to very much lower levels of, for instance, below 60,000 and 50,000 p.s.i. in tensile and yield strengths. In fact, 50 percent of forgings processed in a routine fashion will exhibit tensile and yield strengths of below 65,000 and 55,000 p.s.i. In a forging of the general type described here, an improvement of 4,000 or 5,000 p.s.i. in minimum strength is considered highly significant and well worth any reasonable effort to achieve such. Several different furnace treatments are now performed to verify that the thermal effect accumulation method can accurately reproduce the optimum strength effect.

In a laboratory furnace, one such forging is brought in 1 hour to a temperature of 360° F. where it is held for approximately 3½ hours after which the treatment is interrupted

because of the counter indicating that the treatment has ended. Because of the temperature being above the target temperature and the accelerated aging effects associated therewith, the total time in the furnace, including heat-up, was only 4½ hours. During the 1-hour heat-up, the forging undergoes the aging effects of a full hour at 350° F. (T'). The 3¾ hour exposure at 360° F. is equivalent to a 5-hour exposure at 350° F. so that heat-up and hold time effects add up to an equivalent 6 hours at 350°. Tensile test specimens removed from the forging reveal tensile and yield strengths of, respectively, 70 and 60 k.s.i. which indicates excellent agreement with the optimum standard.

Using a large industrial furnace for an identical forging requires 12 hours to heat up to a temperature of 360°. This heat-up imparted the aging effects approximately equivalent to a 4-hour exposure at a temperature of 350°. The forging is held at 360° for only 1½ hours which provides the equivalent effects of an additional 2 hours at 350° at which point the device indicates the treatment is concluded. Thus, the member receives the equivalent aging effects of the ideal 6-hour exposure at 350° F. although it remains in the furnace for a total of 13½ hours but spends only 1½ hours at the hold temperature. The member again exhibits tensile and yield strengths of 70 and 60 k.s.i. An additional member is permitted to remain at the 360° F. temperature for the full 6-hour "hold" time. It exhibits tensile and yield strength values of, respectively, 63 and 53 k.s.i., a marked reduction where the highest possible strength levels are sought.

In all the above runs, the material was treated to an "overaged" condition so that each material possessed immunity to stress corrosion cracking as evidenced by electrical conductivity test mentioned earlier. That is, each demonstrated a conductivity of at least 38 percent of the IACS.

In another test involving the same 4-inch thick forging mentioned above, the member was heated to only 340° which is considered within the commercial tolerance range of a 350° target. It was observed that it took 1½ hours for the member to reach the 340° F. temperature where it was held for 8½ hours at which point the counter indicated that the treatment was concluded. The heat-up stage was equivalent to one-half hour aging at 350° and the 8½ hour hold time was equivalent to 5½ hours at 350° F. Tensile specimens removed from this piece again exhibited tensile and yield strengths of 70,000 and 60,000 p.s.i. The electrical conductivity of the forging was 39 percent of the IACS. In another run, an identical forging was heated to 340° F. in 1½ hours and held at that temperature for the 6-hour prescribed period. The 6-hour hold time is really equivalent to only 4.5 hours at 350° F. While the tensile specimens removed from the forging exhibited adequate strength, the material exhibited an electrical conductivity somewhat less than the 38 percent IACS minimum necessary to indicate satisfactory immunity to stress corrosion cracking.

In the foregoing examples, the ideal hold time at the target temperature of 350° F. was 6 hours. In those treatments employing the invention, the furnace hold times varied from 1½ to 8½ hours and the total furnace residence times from 4¼ to 13½ hours. The properties in these instances agreed precisely with the desired optimum properties even though the furnace hold times varied markedly from the ideal 6-hour value. In fact, the only instances employing the 6-hour hold time resulted in failure to achieve the desired properties. This illustration clearly demonstrates that the practice of the invention enables achieving the desired effects of a thermal treatment even though the temperatures vary somewhat from the target temperature and that such is accomplished in a highly repeatable manner.

In addition to aging, there are various other applications in the thermal treatment of metals to which the markedly improved precision offered by the invention will be highly useful. One example of such occurs in the partial annealing of aluminum alloy extrusions which have been cold worked by stretching. It is often desired to partially anneal such extrusions to increase their ductility. However, it is important that

the partial annealing not be over extended to result in excessively reduced mechanical properties. For instance, extrusions of aluminum alloy 5454 or 5456 are strain hardened by stretching them 2 percent of their length. This imparts a considerable hardening effect because of the cold work imparted by this stretching. The extrusions, however, exhibit seriously impaired ductility which can be relieved by proper stabilizing. This is accomplished by heating to a preselected temperature for a certain time. These time and temperature values are determined experimentally to achieve optimum ductility-strength effects. In practice, this optimum is usually overshoot or undershot and the teaching of this invention offers a readily applied solution to this problem by accounting for thermal effects rather than elapsed time.

Yet another field in which the results sought in a thermal treatment soak and diminish with respect to time occurs in thermally treating composite alloy sheets. One example occurs in a sheet having a core of aluminum alloy 6061 clad with aluminum alloy 7072. During the solution heat treatment necessary to achieve maximum strength in the core material, some amount of diffusion occurs between the core alloy and the cladding alloy. All that is normally necessary in solution heat treating of large or heavy pieces is that the time be of sufficient duration to accomplish the desired effects, and a somewhat longer time is not harmful. However, with a composite sheet of the type described, excessive diffusion can impair the properties of the core or cladding or both. Hence, the optimum time-temperature relation necessary to achieve the desired solution effects while minimizing diffusion can be determined experimentally and then the equivalent time-temperature effect is accurately reproduced in commercial operations by the practice of the invention.

It is readily apparent that there are various thermal treatments where competing effects occur such as where one property is increasing while another desirable property decreases. Instances of such may occur in the thermal treatment of metals as discussed above or in the curing of some plastic systems or in various other applications which arise in industry. Hence, the invention may find application in these various areas and it is intended that the scope of the invention apply to such and not necessarily be limited to the particular embodiments described herein.

What is claimed is:

1. In a process of thermally treating a metal body to impart thereto the effect on a certain property of a thermal exposure at a preselected temperature T' for a time t' and in which process the actual metal temperature T of the body varies from the preselected temperature T' the improvement comprising:

1. heating said metal body in a furnace to a metal temperature at which said certain property is responsive which metal temperature T fluctuates and varies from said temperature T',

2. continuing the thermal treatment until the value of K in the following relation reaches a level predetermined for said body with respect to said certain property:

$$E_1 t_1 + E_2 t_2 + E_3 t_3 + \dots + E_n t_n = K$$

where t is the period of time at temperature T and E is the predetermined correction factor for temperature T in terms of equivalent thermal effect at temperature T' said effect predetermined with respect to said certain property,

3. thereupon interrupting said treatment.

2. In a process of thermally treating a metal body wherein a first property is enhanced while a second property is diminished during which treatment the metal temperature varies from a preselected temperature T', the improvement comprising:

1. heating said metal body in a furnace at a relatively slow rate to a metal hold temperature at which said first and second properties are responsive which hold temperature fluctuates and varies from said temperature T', said slow heating rate effecting substantial changes in said properties during said heating to said hold temperature,

2. continuing the thermal treatment until the value of K in the following relation reaches a level predetermined for said body with respect to said first and second properties such that said first property is enhanced to a selected level and said second property is diminished to a minimum extent:

$$E_1t_1 + E_2t_2 + E_3t_3 + \dots + E_nt_n = K$$

where t is the period of time at temperature T and E is the predetermined correction factor for temperature T in terms of equivalent thermal effect at temperature T' said effect predetermined with respect to at least one of said properties,

3. thereupon interrupting said treatment.

3. In a process of thermally treating a metal body to impart thereto the effect on a certain property of a thermal exposure at a preselected temperature T' for a time t' and in which thermal treating process the actual metal temperature T of the body varies from the preselected temperature T' the improvement comprising:

1. heating said metal body in a furnace to a metal temperature at which said certain property is responsive which temperature fluctuates and varies from said temperature T' ,

2. providing a signal output which represents E where E is the correction factor for the actual temperature T of the metal body in terms of equivalent thermal effect at temperature T' predetermined for said body with respect to said certain property,

3. continuing the thermal treatment and accumulating said signal output until the accumulation reaches a value in accordance with the following relation wherein K corresponds to t'

$$E_1t_1 + E_2t_2 + E_3t_3 + \dots + E_nt_n = K$$

where t is the period of time at actual metal temperature T ,

4. thereupon interrupting said treatment.

4. The method according to claim 3 wherein said E signal output is a continuously provided electrical signal.

5. In a process of thermally treating an aluminum body to impart thereto the effects on a certain property of a thermal exposure at a preselected temperature T' for a time of t' which temperature T' follows within the range of 200° to 450° F. and in which thermally treating process the actual temperature T of the aluminum body varies from the preselected temperature T' the improvement comprising:

1. heating said aluminum body in a furnace at a relatively slow rate to a metal hold temperature at which said certain property is responsive which hold temperature fluctuates and varies from said temperature T' said relatively slow heating rate being such as to effect substantial changes in said certain property during said heating,

2. continuing the thermal treatment until the value of K in the following relation reaches a level predetermined for said body with respect to said certain property and corresponding to time t' :

$$E_1t_1 + E_2t_2 + E_3t_3 + \dots + E_nt_n = K$$

where t is the period of time at temperature T and E is the predetermined correction factor for temperature T in terms of equivalent thermal effect at temperature T' said effect predetermined with respect to said certain property,

3. thereupon interrupting said treatment.

6. In a process of artificially aging an aluminum alloy containing zinc, magnesium and copper to achieve high resistance to stress corrosion cracking while minimizing strength loss which effects would be achieved by a treatment at a preselected temperature of T' for a time of t' which temperature T' falls within the range of 315° to 380° F., the improvement comprising:

1. heating a body of said alloy in a furnace to a metal temperature within the range of 315° to 380° F. which metal temperature fluctuates and varies from said T' ,

2. continuing the thermal treatment until the value of K in the following relation reaches a level corresponding to t'

$$E_1t_1 + E_2t_2 + E_3t_3 + \dots + E_nt_n = K$$

where t is the period of time at temperature T , and E is the predetermined correction factor for temperature T in terms of equivalent thermal effect at temperature T' said effect predetermined with respect to strength.

3. thereupon interrupting said artificial aging.

7. The improvement according to claim 1 wherein the Et function is continuously monitored and the relation becomes:

$$\int_{t_1}^{t_n} E dt = K$$

8. The improvement according to claim 6 wherein in said relation in said step 2

$$E = e^x,$$

$$x = \frac{A}{T'} - \frac{A}{T}$$

$$A = 27,942 \text{ and}$$

e is the base of the natural logarithm.

* * * * *